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A model for economic evaluation of alternative waste management systems in Iowa beef cattle feedlots

by

Eldon Leroy Erickson

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CHAPTER I. INTRODUCTION

The Problem

A wide variety of cattle feeding systems exist in Iowa. They range from the relatively large specialized feedlots to the more typical farm feedlot that complements the rest of the farming operation. While feedlots with more than 1000 head are no longer uncommon, Iowa's feedlots in general tend to be considerably smaller than the feedlots of Southwestern United States (41).

Historically, Iowa has been the number one fed cattle producing state in the nation. However, in recent years it has lost this ranking to the southwestern states. It was primarily by means of the smaller farmer-feeder, who integrated cattle feeding into his entire farming operation, that Iowa had achieved its number one ranking. The importance of the smaller feeder in the Iowa cattle feeding industry, and the recent trends to larger feedlots can be seen in Table 1.

Table 1. Cattle feedlots and fed cattle, Iowa (82a)

	1966		1976	
Size of feedlot	No. of feedlots	% of cattle marketed	No. of feedlots	% of cattle marketed
Under 1000 hd.	45,913	95	32,830	86
1000-1999	68	3	79	3
2000-3999	12	1	65	5
4000-7999	>7	1	19	3
8000 and up			7	3
Total	46,000	100	33,000	100

Many things are behind the changes in the cattle feeding industry of Iowa, and the nation. New technologies and varieties of feed grains helped the southwestern states utilize their warm dry climate and greatly increase their fed cattle output. Improved grain prices and the riskiness of cattle feeding has influenced some farmer feeders to "go all grain" and drop out of cattle feeding all together.

Convenience and an increasingly scarce supply of inexpensive farm labor has influenced new cattle feeding technologies to become more capital intensive. Therefore, to be economically competitive, livestock feeding operations which need not be land based, tend to become specialized autonomous units capable of spreading high fixed costs over a large concentrated volume of animal units (8). The result has been increased confinement of livestock and increased numbers of animals per livestock operation. Improved production methods, mechanization, and better disease control and nutrition have made this possible with a minimum increase in labor.

Such changes in the cattle feeding industry have created new problems, which in turn create pressure for more change. In the past, grain and roughage produced on the land went into livestock production, and the manure from the livestock went back on the land. However, the change to confined

livestock production has altered this complementary relationship. In Iowa this relationship has not been changed as much as perhaps the southwestern states. But increasingly, many large confinement operations do not produce enough feed from their own land and import feed from adjacent farms. Similarly they do not have enough land under their own control to dispose of the wastes produced by their operation. The land area with which many highly capitalized feedlots are associated is no longer capable of utilizing the large concentration of wastes produced and an ecologically unstable environment has been created (52). Thus we can see that as methods of livestock production become more intensive, the relationship between the efficiency of livestock production and potential environmental quality problems become more pronounced. Animal wastes have always been associated with agriculture but have become more noticeable because of large concentrated production units, reduced availability of labor, narrow profit margins, and because land for disposal is becoming less available and more expensive (52).

The practice of managing animal wastes to control pollution began when animals were confined (89). Because todays livestock operations tend to be more confined and continue to increase in size, a higher degree of waste management is required. Also, more waste management is required because social attitudes are changing the definition and degree of

acceptability of environmental pollution. Taste and color, odors, dust, organic and inorganic matter, plant nutrients, insects, and pathogenic bacteria are all pollutional factors which can result from the mismanagement of animal waste.

Because of social concerns about the possible pollution problems created by the advent of large scale, highly concentrated livestock production systems, the United States legislature passed a law in 1972 limiting feedlot pollution. Final regulations by the Environmental Protection Agency (E.P.A.) which came out in late 1973 have exempted those feedlots under the 1000 head scale from applying for discharge permits. Recently, a New York-based environmental group called The National Resources Defence Council filed suit against the E.P.A. for "unlawfully exempting" most farms under the 1000 head scale (1b). Because of the relatively high investment costs involved in complying with the pollution regulations, feedlots under the 1000 head scale may not find it economical to operate if forced to meet effluent guidelines. Thus, the trend toward larger scaled, more highly concentrated feedlots may be fostered by such action (1b).

Both consumers and producers have a stake in the extent to which feedlot pollution is controlled. Costs incurred by producers will eventually be passed on to consumers in the form of higher meat prices or higher taxes. Lack of control may lead to an undesirable environment. Also, pollution

controls may alter the type and size of beef systems used. Discussing the issue of large scale operations and control over markets, Sandquist and Gruither (78) states that:

> Concerns of the general public, including consumers and taxpayers, center on at least four broad issues: 1) they want dependable food supplies of low cost and high quality; 2) they want to curtail agricultural practices that adversely affect environmental quality and the availability of open spaces, 3) they want tax costs of any policy to be in line with the benefits realized, 4) they want a fair share of the benefits of farm programs to accrue to the smaller (as contrasted to large scale) producers. Though some think that large scale farming will be low cost and efficient others think big farm corporations will try to gain monoply controls and raise food prices.

The additional food production costs that would be associated with various levels of pollution control are relatively unknown (51). Additional production costs that are incurred by a substantial number of producers, will sooner or later be reflected in higher food prices. The increase in food costs that the public would have to bear in order to reach desired levels of environmental quality, is one of the major unknowns. The public can decide whether the benefits of environmental quality are enough to justify the costs, only if they have some means of estimating the costs.

Producers are confronted with a two-fold problem in the proper management of livestock wastes. First, the cost and effectiveness of various control measures are sometimes unknown. This problem can be remedied through continued

research and subsequent educational programs. Second, great uncertainty exists regarding the degree of environmental quality that will eventually be demanded by society and the control measures that will be utilized to achieve that quality. Trying to satisfy regulations yet to be specified is a risky business with today's cost of facilities. These problems have placed many livestock producers in a wait-and-see position. They can not afford to do the job twice.

Government officials, consumers and producers are all in need of information about the results of possible pollution control actions. Consumers need to know the cost of an improved environment. Government officials need to know the economic and social effects of pollution control laws they may enact. Producers need to know what acceptable alternatives are available to them and what effect pollution control measures may have on their production costs.

To gain this information actual operating systems could be set up and operated under constant "average" conditions, but this of course would be too expensive and time consuming (if possible at all). A "pass the law now and see what happens later" attitude could be adopted, but this may have some very harsh effects on some of the people involved. Thus it would seem, some sort of simulation model of beef cattle feeding systems would be useful.

Objectives

Society determines the direction of change in any system in accordance with societal goals. The decision, made by trading off desirable and undesirable features of candidate systems, is implemented by the use of economic or legal controls or by the use of some other appropriate social mechanism. Many cattle feeding systems as they now are, are not likely to be satisfactory. Changes will be needed to meet new standards. Research information and analytical techniques are needed to predict the direction the changes will take. What are the costs of desirable and undesirable features of candidate systems?

The first objective of this study was to develop an analytical tool to evaluate beef cattle waste management systems over a range of capacities for a selected set of technologies. There are two ways to approach such a study (35). Actual operating systems using each technology, of sizes distributed over the desired range, could be located and analyzed from information gathered on site. This approach is difficult, if not impossible because comparable systems using the same technology and similar management over a suitable range of sizes must be located. This difficulty is compounded by the necessity of obtaining co-operation from operators after suitable systems have been found. Accordingly, the alternative, a modeling approach was adopted.

The model developed during the course of this study is a heuristic simulation model of various beef feedlot types and their waste handling alternatives. Each segment of the waste collection, storage and treatment, transport and disposal process is simulated in components of the model. In addition the model developes and designs the confinement and shelter facilities for the cattle. Since the variations in technology are practically unlimited, the set of alternatives had to be limited. The technologies chosen for evaluation will be described along with design procedures in Chapter IV. The development of this model is an attempt to provide a tool for analyzing and comparing beef production systems and waste handling alternatives, in terms of certain physical characteristics, for a selected set of technologies and sizes.

The second objective of this study was to utilize this model to evaluate the effect of various restrictions on waste handling practices. Although considerable resources have been focused on the environmental question, the impact of control measures and the cost of producer adoption of alternative pollution abatement technology has received little attention. Information and analytical tools resulting from this study will be useful for providing agricultural interests with information for decision making concerning the economic feasibility of alternative production and waste handling systems, providing nonagricultural interests with the costs of

some pollution abatement options so they can better appraise alternatives, and providing the general public with the tools for choice to assist in the development of an environmental policy.

CHAPTER II. CATTLE FEEDING TECHNOLOGIES

During the early stages of the beef cattle feeding industry, there was little or no emphasis on waste management for pollution control. At that time, the majority of cattle feedlots were located with little regard for pollution potentials. In fact, many feedlots were located to take advantage of natural drainage ways to transport solid and runoff-carried wastes out of the feedlot. However, recent awareness of environmental degradation coupled with ever increasing sizes of individual feedlots and related decreases in available land area for wastes disposal have placed emphasis on the environmental hazards associated with cattle feeding. There have been instances in the past, where lack of proper waste management has resulted in the pollution of surface (and in some cases ground) waters which sometimes resulted in extensive environmental damage and fish kills (61).

Planning for Pollution Control

As pointed out by the NC-93 committee in Livestock Waste Management With Pollution Control edited by Miner and Smith (62), potential pollution problems can be significantly reduced during the initial planning stages of a feedlot. This can be done by the careful selection of production facilities with a corresponding proper waste management system. Some of

the major factors to be considered are: location of the facility, terrain and soil type, climate, type of animal management system, economics, and local, state or federal regulations.

Location

The location of the facility has a large effect on the success of a waste management system. Ideally, as described by Kreis and Shuyler (49), the feedlot should be located in an agricultural area, downwind from nearby residential areas, and on sufficient land area to permit adequate treatment and disposal of the waste materials produced.

Terrain and soil type

Suitable terrain and soil type must be chosen, or needed engineering and earthwork accomplished, so that feedlot runoff will not pollute surface or ground water sources. Diversion of precipitation falling outside the feedlot, lot topography and drainage are factors that must be considered in this area.

Climate

The general type of housing and waste management systems used in a given area are pretty much determined by the climate of that area. Climatic considerations involved are temperature, precipitation, evaporation, wind velocity and direction, and

solar radiation (19, 51). Most of Iowa is considered as being in the cool, wet or cold, wet zones of the United States, as these zones are defined by Butchbaker et al. (12). The cool wet zone is characterized as having an average January temperature between 20°F and 32°F and having excess precipitation over evaporation. The cold, wet zone is characterized as having an average January temperature below 20°F and an excess of precipitation over evaporation. In both cases shelter has a positive effect on animal performance and adequate waste storage must be provided to avoid applying waste to frozen ground.

Animal management systems

Livestock production and management systems vary greatly throughout the United States, and even across Iowa. Beef cattle production systems vary from open-range types with very little designed waste management to total-confinement buildings with a high degree of waste treatment. However, as discussed by Loehr (52), where feedlots are concerned the trend has been towards fewer and larger lots with higher concentrations of animals and consequently, greater waste disposal problems.

Management practices such as oxidation ditches or flushing gutters, affect the amount and quality of waste that has to be handled, as well as the type of handling and treatment

system that can be selected (84). The amount and quality of waste produced by an animal is also affected by the type of ration it is consuming (82a, 30).

Economics

Economics is one of the prime considerations in selecting a waste management system. Various studies and reports (6,10, 12,18,23,74) have been made concerning the resource requirements and costs of individual production and waste management systems. Some systems that require high capital expenditures for facilities and equipment, may have lower operating or variable costs because of low labor requirements. The variable costs also include added fuel, electrical, and maintenance costs. Some of these costs may be "recovered" by the beneficial value of the waste as a fertilizer or for some other use such as refeeding.

Regulations

The increase in environmental pollution has required the enactment of additional legal restraints in the form of state and federal statutes and regulations. Also individual court actions seeking redress for damages are becoming increasingly commonplace.

Federal pollution control legislation has been in existence since the turn of the century, but has been

increasing rapidly since 1948. As reviewed by the Water Resources Council (87), the basic policy of water pollution control in this country is found in the Water Pollution Control Act of 1948 and subsequent legislation. Basically the policy of federal water pollution control legislation includes: (1) Congress has the authority to control pollution in the waterways of the nation, (2) the prevention and control of water pollution benefits both the health and welfare of the nations people, (3) a national policy for the prevention, control, and abatement of water pollution shall be established and implemented.

The scope of federal activities was greatly expanded by the Water Quality Act of 1965 and the federal government has since assumed a leading role in the control of water pollution. The provision for establishing water quality standards was one of the far-reaching effects of the 1965 Act. Each state was given the responsibility of developing water quality criteria and plans for their implementation and enforcement.

A national objective for the elimination of the discharge of pollutants into navigable waters by 1985 was set forth in section 101(a), (1) of the Federal Water Pollution Control Act, as amended by the Water Pollution Control Act Amendments of 1972. Section 306(a) defines "standard of performance" as a "Standard for the control of the discharge of pollutants which reflects the greatest degree of effluent reduction which

the administration determines to be achievable through application of the best available demonstrated control technology, processes, operating methods, or other alternatives, including where practicable, a standard permitting no discharge of pollutants" (75, p. 1). The performance standards specified by the E.P.A. call for retention facilities to control the runoff that can be expected from a rain once in ten years, to be built by 1977; that which can be expected once in 25 years, by 1983.

It is difficult to generalize pollution abatement costs as they are highly situation specific. A regression analysis of investment costs for pollution abatement in beef cattle feedlots in Southwestern Minnesota found that only 39% of the variation could be associated with variation in feedlot capacity (74, p. 37). Only minimal runoff control may be necessary in many feedlots in Iowa where a large proportion of class A land exists. Specific situations, however, may require additional investment in pollution abatement facilities.

Many states have passed laws regulating feedlots and other animal enterprises (43, 55). Most of these states issue permits whenever minimum livestock numbers are reached and whenever compliance with state regulations is achieved. Control of runoff wastes and management of all animal wastes, as well as general sanitation, may be required by these regulations.

CHAPTER III. PRODUCTION FACILITIES AND WASTE MANAGEMENT SYSTEMS

Lot and Shelter

The function of a feedlot is to confine feeder cattle during the finishing phase of growth. For this study a feedlot is considered to consist of the following parts: fence, gates, concrete aprons and floors, waterers, and feedbunks. Feedlots can be completely open, completely sheltered, or partially sheltered and partially open. Shelter and lot size are both directly related to the number of animals to be confined and the space allocated to each.

Open lots are the most common in the southwestern part of the United States. In colder climates, such as Iowa, a variety of feedlot types are used, and animals are often given some shelter. Both completely open and partially open lots may have a "mounded" area for the cattle to rest on during wet weather.

The shelter area can be provided by relatively inexpensive pole type buildings with three walls. In an open feedlot with shelter, the fourth side is open to the unsheltered part of the feedlot. In a "cold" confinement system the cattle are confined inside such a building by a fence along the open side. The air temperature inside the building fluctuates, according to the outside temperature. A "warm" confinement building is

a completely enclosed (four walls), insulated, fan ventilated building with wintertime control over inside air temperature.

Feedbunks can be either the fenceline type or the mechanical (auger) type. Fenceline feedbunks filled from mixer wagons have increased in popularity as the average feedlot capacity has increased. Feedbunk length depends on the number of animals to be fed and the bunk space provided for each animal, which depends on the size of the animal and the number of animals which must eat at one time. Recommendations range from six inches to thirty inches (59).

In order for beef cattle to perform efficiently an adequate supply of water is necessary at all times. Waterers have an upper limit on the number of animals that can be supplied per unit, typically about 75 head. The total number of waterers needed in a feedlot then depends on the feedlot capacity and the number of animals that can be supplied from each unit.

Concrete aprons are usually provided along the feedbunk and in front of the entrance to the shelter area. These aprons are usually from 8 to 15 feet wide.

Fencing is used to confine the animals and to separate them into pens. Usually the number of animals per pen is kept below 200 (16). Since the feedlot is a permanent installation the fences should be substantial.

Gates should be provided for ease of access to the pens and as an aid to moving and controlling the cattle. At least one gate per pen is essential, and the number of additional gates depends on the feedlot type and preferences of the feedlot operator.

Waste Collection

There are several possible methods of waste collection (60). Some of the places where manure collects are; on the feedlot surface, the manure pack in a loafing shed, and a pit or tank under slotted floors or at the end of a flushing flumes system (42).

The manure that falls on an open feedlot surface is susceptible to being carried away in runoff caused by snow-melt or rainfall. In many cases this runoff containing manure must be controlled and collected to prevent pollution problems. This is usually done by techniques derived from soil erosion control practices. This runoff contains not only solids from animal waste but from the feedlot soil surface as well (62). Some of these solids are settled out and collected in settling basins. The remaining solids along with the runoff liquids are collected in holding ponds or lagoons. The size of settling basin and holding pond or lagoon needed is dependent on the size of the drainage area, the physical characteristics of the lot surface, and the amount of rainfall or snow-melt (80).

Part of the process of waste collection involves controlling "clean" runoff. Clean runoff, although not an accurate description, is a useable name for runoff that does not contain manure. This would include runoff from roofs, drives, and grassed or cropped areas (60). This runoff need not be handled as a livestock waste. Clean runoff can be diverted away from waste collection areas to reduce the amount of waste volume to be stored and handled, or it can be diverted into waste collection systems if needed for dilution purposes. Curbs, dikes, terraces, and other soil erosion control techniques are used to control this runoff as desired.

A shelter is an extreme case of clean runoff diversion. Snow and rain are kept from the manure for the most part, so no runoff occurs and no additional volume results from them. However in the case of a manure pack, any bedding used will increase the volume of material that will need to be handled.

In both the manure pack and slotted floor confinement systems the waste collection methods might be termed "self loading" as the animal wastes go directly to storage and/or treatment areas (60). However, the slotted floor system separates the animal from his manure without the use of bedding, and thus no additional volume results, unless dilution water is added to the pit.

In flushing flume systems, the manure falls on concrete floors and is "worked" into slots in the floor and then is "flushed" through flumes to holding ponds or tanks elsewhere. Flumes are the under-floor channels used to carry the flushed manure out of a building. Because of dilution requirements the amount of material to be handled will be greatly multiplied by hydraulic flushing. Unless the flushing liquid is recycled, storage and treatment requirements are similarly increased (60).

Waste Storage and Treatment

Waste storage facilities are often required because bad weather and field conditions may physically prevent the transportation of manure, the odors released when manure is spread may force delays, or the stage of development of crops may prevent spreading. Also under certain weather conditions, the application of manure to land may create potential water pollution problems.

Many types of storage facilities are used, such as: manure stacking structures; manure packs in loafing sheds; holding ponds or lagoons; pits and tanks. Requirements or guidelines for the minimum sizes of these storage structures vary between states because of different climates or need for pollution control (55). Construction, maintenance and use of waste storage facilities also varies from area to area.

The storage capacity required is a function of the number and size of animals, the amount of dilution water added, the amount of runoff to be stored and the desired length of time between emptying. Maximum labor advantage is obtained from large storage units. A storage capacity of three to six months is desirable and may be required to avoid spreading manure on frozen or snow-covered ground, or on crops (60).

Livestock waste may be treated or processed in several ways to modify its physical and chemical characteristics and to reduce its pollution potential (62). In many cases waste treatment takes place concurrently with storage.

Biological treatments can be classified as either anaerobic or aerobic. Anaerobic systems contain bacteria that can live in the absence of dissolved or free oxygen, whereas aerobic systems contain bacteria that require dissolved or free oxygen. Since naturally aerobic lagoons require extremely large surface areas and often high dilution of the waste, most livestock waste lagoons are anaerobic. Because of odor reduction possibilities more and more mechanically aerated lagoons are being used. An oxidation ditch is another form of aerobic treatment. This method mixes atmospheric oxygen into the liquid waste by the use of a rotor (63).

Numerous other biological, physical and chemical processes may have application to specific waste fractions (62). In general though, many of these methods are too specific and/or expensive for practical use in most feedlots at this time.

Waste Handling

Periodically manure and waste water have to be moved from storage and treatment areas to the utilization area. Manure must be removed from sheds and stacking areas, manure tanks must be pumped, and holding ponds must be emptied and lagoon levels lowered.

Methods of transporting manure or lagoon effluent generally include manure spreaders, liquid manure tankwagons, and irrigation systems (73). Since the manure handling system is an integral part of the entire livestock waste management system, the method of handling desired must be considered when the entire system is designed. The way in which manure is collected, stored and treated has a lot to do with how it can be transported. Confinement operations in which liquid manure is stored in a pit may utilize either a liquid manure tankwagon or a manure gun sprinkler system. Where lagoons are used with confinement or open livestock facilities, the manure will be liquefied and kept in suspension by the lagoon activity so that this material may be handled

through conventional irrigation systems or liquid manure tankwagons. The solids remaining on an openlot surface, and the material in a manure pack are usually loaded into a conventional manure spreader by a front end loader.

Initial and maintenance costs will also affect the selection of equipment in a waste handling system. Flexibility for expansion is another thing to consider. For instance, liquid manure tankwagons have the flexibility of hauling additional manure to more distant fields without purchasing additional pipe.

Waste Disposal

No matter what storage, treatment, and handling methods are used in a waste management system, some end products still remain to be disposed. Depending on the situation these end products are either valuable resources to be utilized, or unwanted wastes to be disposed of efficiently. During the past decade, farmers have had little economic incentive to be concerned about nutrient recovery from manure. Most have selected manure management systems based on maximum efficiency and/or minimum cost. However, because of the need to avoid environmental pollution, and the increasing cost and scarcity of commercial fertilizers, an increasing number of farmers are becoming interested in substituting manure for synthetic fertilizer in optimizing crop yields (62).

As with each of the other components of a waste management system, waste disposal is an integral part of the system. In some cases the end use of wastes often dictates the rest of the waste management system (60). Pollution and nuisance potential, economy, and fertilizer value are just some of the things that must be considered. The cheapest method of disposal may not meet regulations or the approval of neighbors.

For most livestock operations the most practical solution is to utilize the manure for an economic return, or at least to minimize costs. Using livestock manure for fertilizer and soil conditioning is the most common practice in Iowa. Disposal of livestock manure by land application is a very old practice, but is still widely accepted as an excellent disposal method (51). However, the application of manure to land may have both beneficial and adverse effects. The physical, chemical, and biological properties of the soil may be altered. Under poor soil and water management practices, livestock manure can create a pollution problem especially from the nutrients lost in runoff and soil-water percolation. Excessive nitrogen application may cause groundwater pollution by nitrates. High application levels of phosphorus, potassium and sodium may also pollute soil and water. These problems can be minimized by sound soil and water conservation practices including erosion control, and possibly pretreatment of the wastes (51).

The nutrient content of livestock manure is a determining factor in the amount of manure that may be applied for either crop production or solely for land disposal. The nutrients in livestock manure varies depending on many factors such as the type of feed, age of the animal and type of the animal (82). Data on the nutrient content of specific animal wastes should be used as guidelines in determining how much manure to apply to the land.

Although most livestock waste is applied to agricultural land, other alternatives are available for the disposal and utilization of this waste product (62). In addition to land application, product recovery techniques include use as fuel, building products, compost and feed supplement. Examples of disposal where the product is not utilized in any way are incineration and deep burial.

CHAPTER IV. SYSTEM MODEL

The model developed during the course of this study does not involve an objective function to be optimized. Optimizing objective functions is not required, nor typically involved in simulation models (1a). The model herein developed is more nearly an empirical tool to be used to evaluate the consequences of different courses of action or policies. Before an evaluation of potential policies or courses of action can be made it is first necessary to simulate the system or entity to be experimented with or evaluated (1a). Therefore the following model is an attempt to simulate various types of cattle feeding facilities and their waste handling alternatives.

In this chapter the model will be discussed in five basic sections: lot and shelter, waste collection, waste storage and treatment, waste handling, and waste disposal. Of course some general assumptions are applicable to all sections, and the sections are interdependent. The general assumptions and calculations will be discussed first and then each section in more detail.

General Assumptions

All calculations involving the capacity or production of the feedlot are based on animal units and animal unit days. One animal unit is assumed to equal one 1000 pound beef animal. One animal unit day is assumed to be one animal unit in the

feedlot for one day. For this study animal units (AU) and animal unit days (AUD) are calculated as follows:

$$AU = \frac{\text{Actual weight of a beef animal}}{1000}$$

$$AUD = \frac{AW \times NA \times DO}{1000}$$

where: AW = average weight of the animals in the feedlot

NA = number of animals in the feedlot

DO = number of days the feedlot is occupied annually.

Fixed cost calculations are based on the cattle feeding system operating at full design capacity. That is, if a farmer decides to build a feedlot for 1000 animal units, his annual fixed costs will be based on the space required and the manure produced by 1000 animal units in that feedlot for 360 days. Three hundred sixty days is assumed to be the maximum number of days that a feedlot will be occupied during any one year period. The size and number of machines and facilities (and thus the amount of investment) is determined by the design capacity of the feedlot and the amount of time assumed available for waste disposal. The assumed cost of capital and economic life of the facilities and equipment also affect the fixed cost calculations. Thus:

$$FC = f(DC, DD, EL, CC)$$

where: FC = fixed cost

DC = design capacity

EL = economic life of the equipment

CC = cost of capital

DD = disposal days available.

These four parameters are all variable in the model.

Variable cost calculations are based on the actual usage of the feedlot. Thus if the 1000 animal unit feedlot were only operating at 80% of capacity, annual variable costs would be based on 288,000 animal unit days.

Underlying the calculations of equipment and facilities needed to handle the manure produced, are the basic assumptions about the quantity of manure produced by an animal unit and the fertilizing elements it contains. This is of course a function of the ration fed to the animal, but for this study the values given by Taiganides and Hazen (82a) are used.

Total wet manure	64 lb/day
Nitrogen	0.38 lb/day
P_2O_5	0.11 lb/day
K_2O	0.31 lb/day

Various storage and treatment methods will affect these quantities differently. The following proportions of fertilizing elements, given by Vanderholm (84) and adjusted for this study with the help of Stewart Melvin (59a), are assumed to be left after treatment and/or storage.

	Nitrogen	P_2O_5	K_2O
Oxidation ditch - anaerobic lagoon	0.16	0.50	0.70
Deep pit storage	0.67	1.00	1.00
Anaerobic lagoon	0.22	0.50	0.70
Aerobic lagoon	0.22	1.00	1.00
Liquids from open lot	0.10	0.05	0.10
Solids from open lot	0.33	0.95	0.90
Bedded confinement	0.66	1.00	1.00

Lot and Shelter

A computer model was developed with subroutines to design and calculate the costs of the following facility options.

Cold confinement: (1) deep pit
(2) flushing gutter
(3) oxidation ditch
(4) solid floor - manure pack

Open lot: (1) no shelter
(2) windbreak fence
(3) open front shed
(4) windbreak fence and open front shed

The building shell of the cold confinement systems and the open lot open front shed are identical. Costs per square foot for various sizes of these types of buildings were obtained from various suppliers. Least squares regression was then used to develop a mathematical equation that "looked like" it fit the

available data. The cost data were too limited to obtain a statistically significant equation. The equation used to estimate building costs per square foot is:

$$Y = 0.006X^2 - 0.1839X + 3.2; \text{ for } 2500 \text{ sq ft} < X < 15000 \text{ sq ft}$$

where: Y = building cost per 1000 square foot

X = total building square foot.

The amount of space allowed per animal unit in each of the different systems is an input that may be varied, but for the options evaluated herein the following values were used. Twenty square feet of shed space was allowed per animal unit for the openlot system. Twenty-five square feet was allowed per animal unit for the cold confinement--solid floor--manure pack system. For the rest of the cold confinement systems 18 square feet of pen space was allowed per animal unit.

In the openlot and manure pack systems the space allowed for animals (shed space in the openlot system), corresponds with the building size. That is, the total building square feet is just the number of animal units times the square feet allowed per animal unit. However, in the rest of the cold confinement building systems, the allowance for a driveway for feeding equipment along one side of the building increases the total building square feet in relation to the space allowed for animals. Therefore the following procedure was used to calculate total building square feet.

First it was assumed that the alley width was 14 feet and that the cattle area was 36 feet wide. Therefore the total building width was 50 feet.

Then:

$$NAUPW = \frac{36 \text{ ft}}{\text{sq ft allowed per AU}}$$

$$BL = \frac{TAUPB}{NAUPW}$$

$$TBSF = 50 \times BL$$

where: NAUPW = number of animal units per width of animal area

BL = building length

TAUPB = total number of animal units per building

TBSF = total building square feet

Fenceline type feedbunks are assumed to be used in all systems. The bunk space allowed per animal unit may be varied from 6 to 30 inches in the open lot system. For confinement systems feedbunk space is determined by the building length. One waterer is provided for each 75 animal units. In the open lot system concrete aprons 10 feet wide are provided around the waterers, along the feedbunks and in front of the open-front shed.

In the openlot system the lots are "stacked" in rows with cattle alleys and feeding alleys between the rows. The cattle

alleys also serve as drainage "channels" for feedlot runoff. The fence is made of wooden posts and cables, except where fenceline feedbunks, windbreak fence, or gates are provided. Two gates per lot are assumed. Shelter may be provided along the north and west sides of the lot. Dirt mounds are provided for animal comfort during wet weather.

The number of animal units per lot, square feet of lot space per animal unit, shelter space per animal unit, number of feet of windbreak fence per animal unit, and number of lots per row are all input variables. In the cold confinement systems the number of square feet of space per animal unit is an input variable. Also, the depth of pit may be either 8, 10, or 12 feet, in the deep pit design.

Generally the loss in value of an asset is determined by its use, obsolescence, and years of remaining life. The kind of asset and the use which is made of it, determines the importance of each of these factors. Buildings and facilities usually lose more value because of age and obsolescence than by use. They will decline in value almost as rapidly when not used as when used (13b). For this study annual fixed costs on buildings and facilities are assumed to consist of: depreciation, taxes, interest, repairs, and insurance. These are lumped together and assumed to be 18% of the initial cost of the system. This does not consider machinery and equipment used to handle and dispose of the manure, these costs are

considered elsewhere.

Waste Collection

As mentioned in the previous chapter, both the manure pack and slotted floor confinement systems may be termed "self loading" as the animal wastes go directly to storage and/or treatment areas. In these cases the calculation of the costs of waste collection is inseparable from either the lot and facilities section of the waste treatment and storage section.

The open lot system involves some distinct manure collection problems. The system may operate with various degrees of manure collection procedures. And the addition of rain and snowfall to the system compounds the runoff and collection problems.

Cattle feedlot studies in eastern Nebraska (27) have indicated that runoff is more dependent on rainfall than of feedlot slope or cattle density. Individual rainstorms produced runoff amounts ranging from 0 to 72% of the rainfall. Annual runoff, including snowmelt was approximately 40% of the total annual precipitation. The amount of runoff resulting from rain depended mainly on the condition of the feedlot surface as determined by previous rainfall events, and rainfall intensity and duration. Runoff resulted from storms producing rainfall amounts greater than .4 inch for all lots

studied.

Runoff resulting from winter thawing conditions indicated that high density lots (100 square feet per head) yielded 130-170% greater runoff quantities than low density (200 square feet per head) lots. High density lots yielded runoff averaging 81% of the precipitation in the form of snow. Low density lots yielded an average of 54% of rainfall equivalent snowfall. Feedlot slope did not appear to affect the quantity of runoff from snowmelt.

Material removed by runoff, from all feedlots studied, averaged .58 tons per acre-inch of rainfalls which produced runoff. Runoff itself transported an average of 1.3 and 1.7 tons per acre-inch for low and high density feedlots respectively.

Solids removed in winter runoff averaged 7.0 tons per acre-inch of runoff for low density lots and 20 tons for high density lots. This resulted from 3.3 inches of precipitation accumulated in the form of snow.

Based on these eastern Nebraska studies, Butchbaker et al. (12) devised a procedure for designing settling basins. The method used in this model is an expansion of that procedure.

To determine the design volume for a settling area, one has to have knowledge of the amount of settleable solids in the runoff. Also a certain volume of water or liquids in the settling area has to be contained to slow up or detain the

runoff to permit the solids to settle out. A suggested design criteria is to add the volume of settleable solids to the volume of a one inch runoff for the feedlot area (12). The steps are then as follows:

I. Design procedure for storage volume required.

A. Determine the total settleable solids that may need to be stored for a given amount of time.

1. Determine the drainage area in acres, AC.
2. Determine the accumulated precipitation for the period, in inches.
3. Determine the runoff from the drainage area, in acre-inches, for winter and summer periods (periods 1 and 2).

Period 1 (November - April):

$$R1 = (AC \times NOVR \times .4) + (AC \times WR \times .5) + (AC \times APRR \times .4)$$

$$= (.4NOVR + .5WR + .4APRR)AC$$

where: NOVR = November precipitation
WR = December - March precipitation
APRR = April precipitation
AC = Area in acres

Period 2 (May - October):

$$R2 = AC \times SR \times 0.40$$

$$= (0.4SR)AC$$

where: SR = summer (May - October) precipitation
AC = area in acres

4. Determine the solids in each periods runoff, in tons.

   Period 1:

   WST = R1 x 7.0 tons/acre inch

   where: WST = winter solids

   Period 2:

   SST = R2 x 1.3 tons/acre inch

   where: SST = summer solids

5. Determine the settleable solids for each period, in tons. (Nebraska results found approximately 50% of the settleable solids settled out in a basin.)

   Period 1:

   WSS = WST x 0.50

   where: WSS = winter settleable solids

   Period 2:

   SSS = SST x 0.50

   where: SSS = summer settleable solids

6. Determine the volume of the settleable solids for each period, in cubic feet.

   Period 1:

   WVSS = WSS x 32.05

   where: WVSS = winter volume of settleable solids

   Period 2:

   SVSS = SSS x 32.05

where: SVSS = summer volume of settleable solids

7. Determine storage capacity needed by determining the largest volume requirement, either WVSS or SVSS.

SV = largest of WVSS or SVSS

where: SV = storage volume required

II. Design procedure for major storm volume requirement.

A. Determine the settleable solids produced by a major storm.

1. Determine the drainage area in acres, AC.
2. Determine the design storm rainfall, DR, 10 year one-day or 5 year two-day.
3. Determine the runoff from the drainage area, in acre-inches, due to this major rainfall event.

R = AC x DR x 0.70

where: R = runoff in acre inches

4. Determine the solids in the runoff, in tons.

ST = R x 1.3 tons/acre-inch

where: ST = solids in tons

5. Determine the settleable solids, in tons.

SS = ST x 0.50

where: SS = settleable solids, in tons

6. Determine the volume of the settleable solids, in cubic feet.

VSS = SS x 32.05 cubic feet/ton

where: VSS = cubic feet in settleable solids

B. Determine the volume of a one inch runoff from the feedlot area.

$$VF = (AC \times 43560)/12$$

where: VF = cubic feet of runoff

C. Determine the design volume for the settling basin for a major storm runoff, in cubic feet.

$$V = VSS + VF$$

where: V = design volume in cubic feet

III. Calculate the total design volume required.

A. The total design volume for storage and a major rain storm, including a sufficient volume for holding a one inch water runoff, is then:

$$TDV = SV + VSS + VF$$

where: TDV = total design volume in cubic feet

B. Calculate the total design volume in cubic yards.

$$TDVY = TDV/27.0$$

where: TDVY = total design volume in cubic yards.

In this model the precipitation amounts are variables so that the model can accommodate the various rainfall amounts that occur over the state.

Included in the waste collection system is the "clean" water diversion system calculations. The diversion system is needed only for the open lot systems and is a diversion terrace constructed around the "upper" side of the lot system.

It is considered to be "needed" on three sides of the lot area, and diverts the "clean" runoff away from the waste collection and storage areas.

Waste Storage and Treatment

The only aerobic treatment considered in this study is the oxidation ditch. This method is considered only in the cold confinement slat floor system, where the animal waste "self loads" into the raceway under the slats. Paddlewheel areators are utilized to incorporate oxygen into the liquid and keep the mixture moving in the raceway. Additional water must be added to the ditch to keep the mixture at the proper consistency. Periodically the ditch must be lowered, and this treated mixture is then stored in an anaerobic lagoon until it can be disposed of onto the land.

In the cold confinement deep pit system the manure again "self loads" into its treatment and storage area. The pit under the slats may be either 6, 8, or 10 feet deep. This variance is necessary to allow for additional storage time if needed. While in this pit the manure under goes some anaerobic treatment, and some of the fertilizing elements are "lost."

The cold confinement manure pack system is also "self loaded." The manure lays where it falls, however, and in order to maintain a suitable environment for the cattle, some form of bedding such as straw must be added to the area. This adds

more material to be stored and handled, and of course is an additional cost. While in the pack the manure undergoes some change, so that the material taken out is not the same in fertilizing nutrients. The added bedding of course changes this value also.

There are two basic lagoon systems, considered in this study. There are the retention lagoon and the anaerobic lagoon. Basically they differ only in size and what happens to the waste while in storage. The retention lagoon is only large enough to hold the volume of wastes, dilution water, and runoff. The anaerobic lagoon has additional volume, so that a favorable environment can be maintained for anaerobic bacteria.

Anaerobic lagoons liquefy and break down manure solids and can handle high loading rates, but do give off some septic odors. Because it is not practical to have complete treatment of the wastes, the lagoons must be pumped periodically. A volume of waste, runoff and rainfall is held in a design storage volume on top of the lagoon's operating design volume and this storage volume must be reduced by pumping periodically to avoid overflow. If necessary, water must be added to maintain the lagoons design volume. Lagoons function best above 70°F and bacterial activity nearly stops at freezing. Cold climate lagoons require more volume than ones in warm climates.

For this model an anaerobic lagoon is considered to consist of the following sections: Minimum design volume

(DESV), dilution volume (DILV), livestock waste volume (LSWV), and a 25 year - 24 hour storm volume (STMV). These volumes are calculated as follows (60).

I. Minimum design volume provides enough space for adequate bacterial populations. This volume must always be maintained.

DESV = 6 cu ft/lb x AUSS x AWT

where: AUSS = designed animal unit space

AWT = average weight of the animals

II. Dilution volume is the amount of water that must be added to the lagoon so that it will function properly. Because of the strength of livestock wastes, mineral and wastes become too concentrated and the lagoon malfunctions unless it is diluted regularly.

DILV = ½ x DESV

III. Livestock waste volume is the total volume of manure that enters the lagoon between pumping periods.

LSWV = TGM/7.5 gal/cu ft

where: TGM = total gallons of manure produced between pumpings.

IV. In addition to the above volumes, a safety margin is included to prevent any overflow from anything less than a 25-year, 24-hour rain on the lagoon surface when the lagoon is nearly full and before pumping starts.

$$STMV = (DR/12.0) \times LAGA$$

where: DR = design storm rainfall = 5.5 inches

LAGA = lagoon area in sq ft

V. Lagoon total volume.

$$TLV = DESV + DILV + LSWV + STMV$$

The volume of a retention lagoon basically has two determining factors: the volume required for storage during periods when dewatering is not possible; and the volume required to contain the EPA-specified 25-year, 24-hour storm. Major storms of this type generally occur during the warm seasons of the year, and dewatering is generally not possible during cold seasons of the year, so these two volumes are not necessarily additive. Selection of the larger of these two volumes as the design criteria would seem to be a practical compromise in most situations.

In this model a linear equation given and discussed in Miner and Smith (62, p. 29f), is used to calculate cold season volume requirements, which is assumed to be larger than major storm requirement. The method used is as follows:

$$ROF = 0.8CSR - 0.5$$

where: ROF = runoff volume

CSR = cold season precipitation

The values of 0.8 and 0.5 give a conservative basis for design.

Waste Handling

The waste handling equipment considered in this study includes, conventional manure spreaders, liquid manure tank-wagons, manure pumps, irrigation systems, and the tractors and/or power to operate these machines. The fixed costs of owning these machines are assumed to be; 1) depreciation, 2) cost of capital, 3) taxes, 4) insurance, and 5) housing and maintenance facilities. The variable costs of owning these machines are assumed to be; 1) repairs and maintenance, 2) fuel, 3) lubrication, 4) operator labor, 5) tractor or power cost. Utilizing the tables and values given by Ayres (4) and the waste volumes calculated by previous sections of this model, equations were developed to calculate these costs. Fixed costs are based on the feedlot operating at full design capacity and variable costs are based on the actual number and size of animals in the feedlot. The cost of capital may be either 8, 10, or 12%, and the economic life of the machines may vary from 5 to 8 years.

The amount and size of waste handling equipment required is a function of; the amount of manure to be disposed of, the distance it must be transported, and the amount of time available for its disposal. The amount of manure to be disposed of is determined in the model by the number and size of the cattle in the feedlot. The distance manure must be transported is a function of the amount of land required for

disposal, which depends on the quality and quantity of manure to be disposed of, and the amount of fertilizing nutrients allowed per acre. In this model it is assumed that the transport distance will be twice the distance from the periphery to the center of the amount of land required for actual manure disposal or possible manure disposal depending on whether variable or fixed costs are being calculated. That is,

$$TT = 2(((AR/3.14)^{\frac{1}{2}}/880))$$

where: TT = transport time

AR = area required for waste disposal, ft^2

assuming: transport speed = 10 mph or 880 ft/min

loading time = 5 min/load + 2 min/1000 gal

unloading time = 3 min/1000 gal

The amount of time available for disposal is an input variable that must be fed in to the model.

Tables 2 through 4 give the assumed sizes, cost and size of tractor needed to operate manure spreaders, liquid manure tankwagons, and vacuum liquid manure tankwagons. These assumptions are based on manufacturers information and recommendations.

As in "real life" the machine inputs in this model are "lumpy." That is, there are limited sizes of machines to chose from, and it is unlikely that the hauling capacity needed will ever exactly match the hauling capacity provided by a selection

Table 2. Conventional manure spreaders. Size, price and tractor size needed

Size in cu ft	Price ($)	Tractor size needed (HP)
125	1500	40
150	1800	50
175	1900	60
200	2000	70
250	2500	80
300	3300	90
350	4200	100

Table 3. Liquid manure tankwagons. Size, price and tractor size required

Tankwagon size (gal)	Price ($)	Tractor size (HP)
1000	2500	60
1500	3400	70
2300	5100	95
3000	5600	110

Table 4. Vacuum liquid manure tankwagons. Size, price and tractor size required

Tankwagon size (gal)	Price ($)	Tractor size (HP)
750	2700	55
1000	3000	60
1300	3500	65
1500	3900	70
2300	5700	95

of manure spreaders or tankwagons. A mix of three different sizes of manure spreaders or tankwagons is possible in this model. This allows for a reasonably close matching of capacity needed and capacity provided. Of course capacity provided always exceeds capacity needed.

Hauling capacity needed is that capacity needed to dispose of the total "possible" manure in the alloted amount of time. Total "possible" manure is the amount of manure produced with the lot operating at full capacity.

After the number and sizes of manure spreaders and tankwagons have been determined, the total "actual" hours each will be used is calculated. This is calculated from the "actual" manure produced. That is, it takes into consideration the actual utilization of the feedlot. This provides the information necessary to calculate annual variable costs.

In certain situations, such as the deep pit storage system, the vacuum pump of a vacuum tankwagon is insufficient to draw out the manure. In these situations an impeller type pump must be used in conjunction with a liquid manure tankwagon. The number of pumps required is determined in a manner similar to the manure spreaders and tankwagons. However, only one size pump is assumed, with a pumping rate of 1000 gallons per minute. Only 50% efficiency is assumed due to agitating, starting, stopping, and aligning tankwagons, etc. The assumed price of a liquid manure pump is $2800.

The conventional manure spreaders are assumed to be loaded with a tractor and manure loader. It is assumed that there are three different sizes of manure loaders available. The assumptions about these loaders are given in Table 5 (23b). The number and size of manure loaders required is determined by the manure spreader requirements. It is assumed that an average of one dump per minute is deposited in the manure spreaders, by the manure loaders. Annual fixed and variable costs are calculated similarly to the other equipment.

Another way of handling wastes is with an irrigation system. In this model two possible systems are assumed. They are the stationary big gun and the traveling big gun systems. These systems are applicable to many waste disposal problems (60). The systems differ mainly in labor requirements and initial costs. In the stationary system a single large sprinkler is moved by hand from one area to another. It will cover about 2.2 acres per set and requires about 70 minutes to move from one set to another (60, 53). The traveling big gun is similar to the stationary system except that the single large sprinkler is mounted on a running gear that is pulled across the field by a cable. These systems are designed to move either 660 ft or 1320 ft on each set and have variable speeds to control application rates. They are fed by a flexible hose which drags along behind the gear. This hose is relatively expensive and makes up a major part of the initial

Table 5. Manure loaders. Size, price and tractor size required

Small size manure loader:

- Lift capacity of 2000 - 2400# to at least 9 ft high
- Breakout force of at least 2800#
- Materials bucket capacity of 13 cu ft., 50 in. wide, with tines
- Bucket level indication
- Mounting stand
- For use on 70 hp, or less, tractors
- Estimated initial list price: $1600

Medium size manure loader:

- Lift capacity of 2800 - 3200# to at least 10 ft high
- Breakout force of at least 4000#
- Materials bucket capacity of 16 cu ft., 72 in. wide, with tines
- Bucket level indicator
- Mounting stand
- For use on medium size tractors, 70 - 120 hp
- Estimated initial list price: $1850

Large size manure loader:

- Lift capacity of 3500 - 4000# to at least 12 ft high
- Breakout force of at least 5000#
- Materials bucket capacity of 21 cu ft., 84 in. wide, with tines
- Bucket level indicator
- Mounting stand
- For use with tractors of 95 hp or more
- Estimated initial list price: $2000

cost of this system. A common size of traveling big gun irrigates about 10 acres per set and requires about 60 minutes to move from set to set (60, 53). It was assumed that a traveling big gun system would be used in feedlot systems with more than 1200 animal units.

Pump size is determined by the volume of wastes to be pumped and the length of time available for pumping. In this model five sizes of pumps are assumed available, they are given in Table 6. Their cost and other data are taken from Lorimor (53) and were expanded and adapted for this study with the help of Stewart Melvin (59a).

Table 6. Irrigation system: Sizes and costs

	Pump discharge (gpm)				
	100	200	300	400	500
Pump cost ($)	825	1000	1175	1350	1525
Pipe size req. (in. dia.)	3	4	5	6	7
Pipe cost ($/ft)	1.00	1.50	2.00	2.50	3.00
Head loss per 100 ft (PSI)	1.4	1.4	0.9	0.7	0.5
Stationary big gun cost ($)	400	500	575	650	700
Traveling big gun cost ($)	6900	7700	8500	9300	10100

Pump discharge and pressure determine the power requirements of the system. The power requirements may be calculated as follows:

$$IHPR = \frac{PCGM \times PREQ}{3960 \times PE}$$

where: IHPR = horse power required

PCGM = pump discharge in gallons per minute

PREQ = pressure required in feet of water

PE = pump efficiency, assume to be 65%

Power for the operation of the waste handling equipment is assumed to be supplied by standard two wheel drive tractors. The costs of this power is included in the variable costs of the waste handling equipment. These costs are calculated using initial list prices for new tractors. The initial list prices are calculated from the following equations derived by Fulton (22b).

$$ILP = 1519 + 143.1 \text{ (PTO) for PTO} \leq 70$$

$$ILP = 7271 + 111.3 \text{ (PTO) for PTO} > 70$$

where: ILP = Initial List Price

PTO = Power takeoff horse power

Annual tractor (or power) costs are then derived as per Ayres (4):

$$TAC = FC + RMC + FC + LC + OLC$$

where: FC = fixed costs = TRT x ILP

RMS = repairs and maintenance costs = 0.008 x ILP x (HRPY/100)

FC = fuel costs = 0.044 x PTO x FP

LC = lubrication costs = 0.15 x FC

OLC = operator labor costs = $3.00/hr

where: TRT = a percent of the list price of the tractor, based on its economic life and the cost of capital

ILP = initial list price

HRPY = hours of useage per year

PTO = tractor power takeoff

FP = fuel price

Waste Disposal

In this model the livestock waste is ultimately disposed of by land application. This is the most prevalent method used in Iowa at this time. In land application the manure may be just spread over the top of the soil, or it may be mixed into the soil, or completely covered by injection under the soil surface. By mixing or covering the manure with soil, odors are reduced and chances of runoff are minimized. Thus a higher degree of environmental protection may be achieved by use of one of these techniques (54). In this model three alternatives are possible: 1) spreading on the surface, 2) mixing with the soil by discing, 3) use of injectors to place the liquid manure under the soil surface.

The fixed and variable costs associated with these methods are calculated similarly to the manure handling equipment. The additional power requirements are supplied by standard two wheel drive tractors, as before.

Table 7. Manure injectors. Costs related to tankwagon size

Tankwagon size, gals	Injector cost, $
750	1300.00
1000	1400.00
1300	1500.00
1500	1600.00
2300	1700.00
3000	1800.00

Table 8. Discs. Size, price, size of tractor needed and acres covered per hour

Disc size ft	Disc cost	Tractor hp needed	Acres covered per hour
14	2730	70	5.90
16	3320	80	6.70
18	3900	95	7.60
20	4500	110	9.60
22	5080	125	10.70
26	6250	150	13.20

In order to have a place to dispose of the manure produced by his operation, a beef feedlot operator needs to have a given amount of land under his control. This may be either by ownership, renting or some contractual agreement for waste disposal on neighboring land. There is the possibility of selling the waste produced, to others for fertilizer but this may be an unreliable method and timing may be a problem.

There are both costs and returns associated with land ownership and control. In this model only the acres required for disposal are calculated, given the varying assumptions about application rates and fertilizing value of the livestock wastes. No inferences are made about the costs or returns associated with land ownership and control.

If crops are produced on the land (as is assumed), there is a positive return from the proper application of manure on the land. This return can be evaluated by considering the amount and cost of commercial fertilizer that would be required to replace the major elements of nitrogen, P_2O_5 and K_2O. The fertilizer value of manure varies, of course. Some manure handling systems result in more nutrient loss than others, as mentioned previously. Whether the manure is stored and handled as a solid or liquid affects the amount of plant nutrients it contains. Also, not all nutrients in livestock wastes are readily available for use by growing plants the first year. Organic forms of nitrogen in manure must be converted to chemical nitrogen before plants can utilize the element (51).

CHAPTER V. COSTS OF ALTERNATIVE WASTE MANAGEMENT SYSTEMS

Part of the concern of the EPA has been with the allowable levels of nutrients that may be applied to soils without runoff and leaching problems. Part of a feedlot operators concern centers around the time he has available to dispose of manure from his operation. Time available for this purpose is affected by weather and the time necessary for other activities such as corn planting, etc.

With these concerns in mind, alternative assumptions were made relative to the amount of nitrogen that may be applied to an acre of land in any one year, and the amount of time available in the spring for the disposal of feedlot waste.

Alternative 1. 250# of nitrogen allowed per acre
14 disposal days available in the spring

Alternative 2. 250# of nitrogen allowed per acre
21 disposal days available in the spring

Alternative 3. 500# of nitrogen allowed per acre
21 disposal days available in the spring

Many other values could have been chosen for these parameters, but these values seemed to be practical and "within the ballpark" and serve for illustrating the use of the model. The remaining parameters were assumed to be at the levels given in Table 9.

Table 9. Values of other parameters

Hours worked per day	10
Interest rate	10%
Life of tractors	7 years
Life of other machines	7 years
Price of fuel	$0.40/gal
April rainfall	3"
Summer rainfall	18"
November rainfall	1"
Winter rainfall equivalent	6"
Design rainfall	5"
Feedlot area (open lot design)	250 sq ft/AU
Feedbunk space	1.5 ft/AU
Shelter area (open lot design)	20 sq ft/AU
Windbreak fence	1 ft/AU
Number of AU per lot	200
Number of lots per row	3
Deep pit storage depth	8 ft
Slat or flume floor confinement area	18 sq ft/AU
Manure pack confinement area	25 sq ft/AU
Oxidation ditch annual operating costs	$0.35/AU/mo
Land	$800/acre
Feedbunks	$8/ft
Posts	$3 ea
cable	$0.50/ft
2 x 6's	$0.40/ft
1 x 10's	$0.35/ft
Concrete	$30/cu yd
Dirt work	$0.40/cu yd
Gates	$75 ea
Springs	$3 ea
Eyebolts	$1.50 ea
Cable clamps	$0.50 ea
Corner braces	$10 ea
Plumbing, electricity	$12.50/AU
Fencing labor	$0.50/ft
Slat flooring	$2.08/sq ft
Flume flooring	$1.75/sq ft
Flushing system	$9500/system

The results of operating the model under the three alternatives stated earlier are given in the tables in this chapter. As mentioned previously no one best or optimum solution prevails. Meaningful comparisons between different systems can only be made after making a specific selection from the options that are available for each system. Most of the feedlot systems have more than one manure handling option available, and the combinations of "ways of doing things" are numerous.

Tables 10-17 give the investment requirements, under the three alternatives, for all of the systems considered. Tables 18-32 give the investment requirements, under the three alternatives, for the options available to these systems. Table 33 lists the annual costs of operation of the feedlot facilities considered. The annual costs for the waste handling and disposal options for each of the available systems, under the three alternatives, are given in Tables 34-51. The total annual costs and costs per animal unit are given for feedlot utilization rates that vary from 50-100% of feedlot capacity.

Discussion of each table in detail would be tedious and is not necessary. As mentioned earlier specific assumptions about the available options are needed before meaningful comparisons may be made. There are too many possible combinations to consider all of them. Two specific situations are used later in this chapter to demonstrate the use of the tables.

In general, certain implications of the systems and their options may be made through the use of these tables. Some of the results are "obvious in everyday life"; others are less so. That confinement systems tend to be more expensive than open lot systems isn't surprising to anyone involved in livestock production. Economies of scale are present--but to any large degree only in about the first 600 head. Limits to scale economies prevail because the model has some "practical" limitations built into it: Because of disease, fire, handling and topographic problems it generally is not practical to have open feedlot pens of 1 square mile in area or confinement barns containing more than approximately 600 head in each barn. These values are personally selected ones and can be varied in the model. The values used in the given runs of the model were chosen after much discussion with feedlot operators, reading many reports from agricultural engineers and animal scientists, and from personal experience.

Because this study emphasizes farmer-feeder operations, large specialized equipment such as endloaders and truck mounted manure spreaders and tankwagons were not included as options in the model. Accordingly, certain options such as manure spreaders and tankwagons reach a point where costs per unit increase as size of feedlot increases. In conjunction with this, the traveling big gun irrigation system just begins to be competitive, in economic terms, at the larger sized feed-

lots. The cut-off point between the stationary big gun and the traveling big gun is an arbitrary one and in retrospect both options should have been allowed to operate over the entire range of feedlot sizes. Then the size of operation at which the traveling big gun becomes more economical under the several alternatives could have been determined.

Two hypothetical situations now are considered to show how the tables can be used to make cost comparisons, or to calculate additional costs incurred due to changes in operation. It is necessary, of course, that the two "farmers" involved are considered to be operating in a world consistent with the assumptions made in this model.

First, consider a southern Iowa farmer who is considering feeding out the calves from his 220 cow herd. He gets around 200 calves, puts them in the feedlot at weaning and leaves them there until finished at 1050 pounds. Therefore their average weight while in the lot is about 800 pounds. They are in the lot for a year. His land is sloping and there is potential runoff to a nearby stream. There are no nearby towns and the feedlot location is at least 1/2 mile from the nearest neighbors, who are also engaged in livestock operations. He is interested in a deep pit confinement system (System #2) or an open lot system with shelter (Systems 4 & 5). He has pasture land available for manure disposal most of the year and is not restricted for disposal time. For comparison

purposes 21 disposal days with 250 pounds of N allowed per acre will be assumed. Injectors and irrigation are not used. From Tables 29 and 31 the following investment requirements are obtained.

Confinement system with deep pit storage	$42,791
Manure pump	2,800
Liquid manure tankwagon	2,500
Total investment	$48,091
Investment per AU capacity	$240.46
Acres of land required for disposal	73
Open lot with open front shed	$20,970
Settling basin and detention lagoon	725
Vacuum liquid manure tankwagon	2,700
Conventional manure spreader	1,500
Manure loader	1,600
Total investment	$27,495
Investment per AU capacity	$137.48
Acres of land required for disposal	47

From Tables 33, 41, 43 and 44 the following annual costs for these two systems with 80% utilization are obtained.

Confinement system with deep pit storage	$7,702
Manure pump	723
Liquid manure tankwagon	1,329
Total annual cost	$9,754
Annual cost per AU	$60.96
Open lot with open front shed	$3,775
Settling basin and detention lagoon	131
Vacuum liquid manure tankwagon	744
Conventional manure spreader	1,221
Manure loader	1,183
Total annual cost	$7,054
Annual cost per AU	$44.09

This comparison shows that for his situation investment costs are about $103 per AU higher and annual costs are about $17

per AU higher for the confinement system. With these costs in mind he can weigh the two alternatives in relation to other advantages and disadvantages of each system. As another example consider a central Iowa farmer with a 1200 head feedlot which drains into a county road ditch. Further, part of his farmland adjoins a small town and he has had some complaints of odors for several days after he has spread manure on this land. He is interested in knowing how much it will cost him to stop the runoff problem and at least reduce the odor complaints. He has a manure loader and conventional manure spreader for cleaning his lots. To reduce the odors from the spread solid manure would require an additional discing operation. He has the disc so no additional investment would be required, but additional annual costs would be incurred. He has a corn-soybeans rotation and is limited for time in the Spring, after the frost goes out and prior to planting. He buys 750-800 lb feeders and feeds them to about 1100#. The lot is kept full year around. His additional investment costs can be obtained from Table 21 and are as follows.

Settling basin and detention lagoon	$2,142
Vacuum liquid manure tankwagon	2,700
Injectors for vacuum liquid manure tankwagon	1,300
Total additional investment	$6,142
Additional investment per AU	$5.12

His additional annual costs are obtained from Table 37.

Settling basin and detention lagoon	$ 386
Vacuum liquid manure tankwagon	1,354
Injectors for vacuum liquid manure tankwagon	284
Discing in solid manure	885
Total additional annual costs	$2,909
Additional annual costs per AU @90% of capacity	$2.69

These are "extra" costs the feedlot operator would have to incur to protect the environment and placate his neighbors. They probably would not improve his product or efficiency. Thus in order to be as "well off" as before he would need to receive an extra 25¢ per hundred pounds liveweight for his finished product.

These are simple examples, but serve to show some of the uses of the model developed during this study. Although the examples are simple they allude to the many "simple" and "complicated" problems we are facing in our environment and society today.

Table 10. Investment requirements for a cold confinement--oxidation ditch system

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$51	$101	$303	$606	$1,212	$2,424
Feedbunks	400	800	2,400	4,800	9,600	19,200
Fencing and gates	1,250	2,500	7,500	15,000	30,000	60,000
Waterers plumbing and electrical	800	1,350	3,000	6,000	12,000	24,000
Open front shed	6,944	12,152	26,873	53,745	107,490	214,980
Oxidation ditch	7,950	15,000	44,100	86,400	169,200	331,200
Rotors	5,000	8,000	15,000	30,000	60,000	120,000
Total costs	26,139	47,391	121,640	241,479	479,358	951,516
Cost per AU	261	237	203	201	200	198

Table 11. Investment requirements for a cold confinement--deep pit system

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$51	$101	$303	$606	$1,212	$2,424
Feedbunks	400	800	2,400	4,800	9,600	19,200
Fencing and gates	1,250	2,500	7,500	15,000	30,000	60,000
Waterers plumbing and electrical	800	1,350	3,000	6,000	12,000	24,000
Open front shed	6,944	12,152	26,873	53,745	107,490	214,980
Slat floor	3,744	7,488	22,464	44,928	89,856	179,712
Deep pit	9,800	18,400	52,800	105,600	211,200	422,400
Total costs	22,989	42,791	115,340	230,679	461,358	922,716
Cost per AU	230	214	192	192	192	192

Table 12. Investment requirements for a cold confinement--flushing gutter system

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$51	$101	$303	$606	$1,212	$2,424
Feedbunks	400	800	2,400	4,800	9,600	19,200
Fencing and gates	1,250	2,500	7,500	15,000	30,000	60,000
Waterers plumbing and electrical	800	1,350	3,000	6,000	12,000	24,000
Open front shed	6,944	12,152	26,873	53,745	107,490	214,980
Flume floor	3,150	6,300	18,900	37,800	75,600	151,200
Flushing system	9,500	9,500	9,500	19,000	38,000	76,000
Total costs	22,095	32,704	68,476	136,951	273,902	547,804
Cost per AU	221	164	114	114	114	114

Table 13. Investment requirements for an open lot system with no shelter

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$574	$1,139	$3,418	$6,836	$13,673	$27,345
Feedbunks	1,200	2,400	7,200	14,400	28,800	57,600
Fencing and gates	2,077	2,696	6,882	13,764	27,528	55,056
Waterers plumbing and electrical	1,250	2,500	7,500	15,000	30,000	60,000
Concrete areas	778	1,333	4,000	8,000	16,000	32,000
Dirt mound	400	800	2,400	4,800	9,600	19,200
Total cost	6,279	10,868	31,400	62,800	125,601	251,201
Cost per AU	62.79	54.34	$52.33	52.33	52.33	52.33

Table 14. Investment requirements for an open lot system with a windbreak fence for shelter

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$574	$1,139	$3,418	$6,836	$13,673	$27,345
Feedbunks	1,200	2,400	7,200	14,400	28,800	57,600
Fencing and gates	1,712	1,886	4,462	8,924	17,848	35,696
Waterers plumbing and electrical	1,250	2,500	7,500	15,000	30,000	60,000
Concrete areas	778	1,333	4,000	8,000	16,000	32,000
Dirt mounds	400	800	2,400	4,800	9,600	19,200
Windbreak	475	945	2,835	5,670	11,340	22,680
Total cost	6,389	11,003	31,815	63,630	127,261	254,521
Cost per AU	63.89	55.02	53.03	53.03	53.03	53.03

Table 15. Investment requirements for an open lot system with an open front shed for shelter

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$574	$1,139	$3,418	$6,836	$13,673	$27,345
Feedbunks	1,200	2,400	7,200	14,400	28,800	57,600
Fencing and gates	2,077	2,696	6,882	13,764	27,528	55,056
Waterers, plumbing and electrical	1,250	2,500	7,500	15,000	30,000	60,000
Concrete areas	778	1,333	4,000	8,000	16,000	32,000
Dirt mounds	400	800	2,400	4,800	9,600	19,200
Open front shed	5,669	10,102	30,307	60,614	121,229	242,457
Total costs	$11,948	20,970	61,707	123,414	246,830	493,658
Cost per AU	$119.48	$104.85	102.85	102.85	102.85	102.85

Table 16. Investment requirements for an open lot system with both a windbreak fence and an open front shed for shelter

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$574	$1,139	$3,418	$6,836	$13,673	$27,345
Feedbunks	1,200	2,400	7,200	14,400	28,800	57,600
Fencing and gates	1,972	2,321	5,777	11,554	23,108	46,216
Waterers, plumbing and electrical	1,250	2,500	75,000	15,000	30,000	60,000
Concrete areas	778	1,333	4,000	8,000	16,000	32,000
Dirt mounds	400	800	2,400	4,800	9,600	19,200
Windbreak fence	286	567	1,701	3,402	6,804	13,568
Open front shed	5,712	10,242	30,725	61,450	122,899	245,798
Total costs	$12,172	21,302	62,721	125,442	250,884	501,727
Cost per AU	$121.72	106.51	104.54	104.54	104.54	104.54

Table 17. Investment requirements for a cold confinement system with a solid floor and manure pack

Investment item	Number of animal units					
	100	200	600	1200	2400	4800
Land	$51	$101	$303	$606	$1,212	$2,424
Feedbunks	400	800	2,400	4,800	9,600	19,200
Fencing and gates	1,250	2,500	7,500	15,000	30,000	60,000
Waterers, plumbing and electrical	800	1,350	3,000	6,000	12,000	24,000
Open front shed	6,944	12,152	26,873	53,745	107,490	214,980
Cement floor	1,250	2,500	7,500	15,000	30,000	60,000
Total costs	10,695	19,404	47,576	95,151	190,302	380,604
Cost per AU	107	97	79	79	79	79

Table 18. Capital investment requirements for system 1 options with 250# of N allowed per acre and 14 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with oxidation ditch	$26,139	$47,391	$121,479	$241,479	$479,358	$951,516
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump(s)	2,800	2,800	2,800	5,600	11,200	14,000
Liquid manure tank-wagon(s)	2,500	2,500	5,100	9,000	20,200	43,800
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,700	3,400	7,000	14,200
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,582	2,871	3,592	13,312	17,824	28,029
Acres of land required for manure disposal	9	18	53	105	210	420

Table 19. Capital investment requirements for system 2 options with 250# of N allowed per acre and 14 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with deep pit storage	$22,989	$42,791	$115,340	$230,679	$461,358	$922,716
Manure pump	2,800	2,800	2,800	5,600	11,200	14,000
Liquid manure tankwagon	2,500	2,500	5,100	9,000	20,200	45,100
Manure injectors	1,400	1,400	1,700	3,400	7,000	15,600
Acres of land required for manure disposal	37	73	220	440	880	1,760

Table 20. Capital investment requirements for system 3 options with 250# of N allowed per acre and 14 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with flushing gutter	$22,095	$32,704	$68,476	$136,951	$273,902	$547,804
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump	2,800	2,800	2,800	5,600	11,200	14,000
Liquid manure tankwagon(s)	2,500	2,500	5,100	10,200	21,400	44,200
Injectors for liquid manure tankwagon	1,400	1,400	1,700	3,400	7,000	15,400
Vacuum liquid manure tankwagon(s)	2,700	2,700	5,700	13,100	29,800	68,400
Injectors for vacuum liquid manure tankwagon(s)	1,300	1,300	2,700	4,800	9,800	20,400
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,702	3,041	3,887	13,937	19,003	30,593
Acres of land required for manure disposal	12	24	72	144	288	578

Table 21. Capital investment requirements for systems 4 and 5 options with 250# of N allowed per acre and 14 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Open lot - no shelter	$6,279	$10,868	$31,400	$62,800	$125,601	$251,201
Open lot - windbreak fence	6,389	11,003	31,815	63,630	127,261	254,521
Open lot - open front shed	11,948	20,970	61,707	123,414	246,830	493,658
Open lot - open front shed and windbreak fence	12,172	21,302	62,721	125,442	250,884	501,727
Settling basin and detention lagoon	471	725	1,679	2,142	5,771	11,136
Manure pump(s)	2,800	2,800	2,800	5,600	11,200	43,800
Liquid manure tank-wagon(s)	2,500	2,500	2,500	2,500	2,500	5,100
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	1,400	1,400	1,700
Vacuum liquid manure tankwagon(s)	2,700	2,700	2,700	2,700	3,000	5,700
Injectors for vacuum liquid manure tankwagon(s)	1,300	1,300	1,300	1,300	1,400	1,700

Irrigation system:						
Stationary big gun:						
100-1199 AU	2,436	2,664	3,235	10,293	11,085	12,203
Traveling big gun:						
1200-4800 AU						
Conventional manure spreader(s)	1,500	1,500	3,000	8,000	20,100	45,000
Manure loader(s)	1,600	1,600	2,000	4,000	10,000	36,000
Disc(s)	2,730	2,730	2,730	2,730	2,730	3,320
Acres of land required for manure disposal	24	47	141	282	565	1,129

Table 22. Capital investment requirements for system 6 options with 250# of N allowed per acre and 14 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with solid floor	$10,695	$19,404	$47,576	$95,151	$190,302	$380,604
Conventional manure spreader(s)	1,500	1,500	3,000	10,000	240,000	546,000
Manure loader(s)	1,600	1,600	2,000	4,000	10,000	24,000
Disc(s)	2,730	2,730	2,730	2,730	3,320	6,250
Acres of land required for manure disposal	36	72	217	433	867	1,734

Table 23. Capital investment requirements for system 1 options with 250# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with oxidation ditch	$26,139	$47,391	$121,640	$241,479	$479,358	$951,516
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tank-wagon(s)	2,500	2,500	2,500	5,000	12,400	28,300
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	2,800	5,000	10,200
Vacuum liquid manure tankwagon(s)	2,700	2,700	3,900	9,200	18,800	42,000
Injectors for vacuum liquid manure tank-wagon(s)	1,300	1,300	1,600	3,200	6,500	13,400
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,582	2,871	3,592	10,800	14,812	20,653
Acres of land required for manure disposal	9	18	53	105	210	420

Table 24. Capital investment requirements for system 2 with 250# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with deep pit storage	$22,989	$42,791	$115,340	$230,679	$461,358	$922,716
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tank-wagon(s)	2,500	2,500	2,500	5,900	13,200	36,600
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	3,000	4,900	10,400
Acres of land required for manure disposal	37	73	220	440	880	1,760

Table 25. Capital investment requirements for system 3 options with 250# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with flushing gutter	$22,095	$32,074	$68,476	$136,951	$273,902	$547,804
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tankwagon(s)	2,500	2,500	2,500	5,900	13,700	30,200
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	3,000	5,000	10,400
Vacuum liquid manure tankwagon(s)	2,700	2,700	3,900	9,200	20,600	45,600
Injectors for vacuum liquid manure tankwagon(s)	1,300	1,300	1,600	3,200	6,900	13,600
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,702	3,041	3,887	11,216	15,696	26,456
Acres of land required for manure disposal	12	24	72	144	288	578

Table 26. Capital investment requirements for systems 4 and 5 options with 250# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Open lot - no shelter	$6,279	$10,868	$31,400	$62,800	$125,601	$251,201
Open lot - windbreak fence	6,389	11,003	31,815	63,630	127,261	254,521
Open lot - open front shed	11,948	20,970	61,707	123,414	246,830	493,658
Open lot - open front shed and windbreak fence	12,172	21,302	62,721	125,442	250,884	501,727
Settling basin and detention lagoon	471	725	1,679	2,142	5,771	11,136
Manure pump(s)	2,800	2,800	2,800	2,800	2,800	2,800
Liquid manure tank-wagon(s)	2,500	2,500	2,500	2,500	2,500	2,500
Injector(s) for liquid manure tankwagon(s)	1,400	1,400	1,400	1,400	1,400	1,400
Vacuum liquid manure tankwagon(s)	2,700	2,700	2,700	2,700	3,000	3,500
Injector(s) for vacuum liquid manure tankwagon(s)	1,300	1,300	1,300	1,300	1,400	1,500

Irrigation system:						
Stationary big gun:						
100-1199 AU	2,436	2,664	3,235	10,294	11,085	12,203
Traveling big gun:						
1200-4800 AU						
Conventional manure spreader(s)	1,500	1,500	2,000	6,000	12,300	29,000
Manure loader(s)	1,600	1,600	2,000	2,000	6,000	14,000
Disc(s)	2,730	2,730	2,730	2,730	2,730	2,730
Acres of land required for manure disposal	24	47	141	282	565	1,129

Table 27. Capital investment requirements for system 6 with 250# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with solid floor	10,695	19,404	47,576	95,151	190,302	380,604
Conventional manure spreader(s)	1,500	1,400	2,000	6,700	15,600	35,400
Manure loader(s)	1,600	1,600	2,000	2,000	6,000	12,000
Disc(s)	2,730	2,730	2,730	2,730	2,730	4,500
Acres of land required for manure disposal	36	72	217	433	867	1,734

Table 28. Capital investment requirements for system 1 options with 500# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with oxidation ditch	$26,139	$47,391	$21,640	$241,479	$479,358	$951,516
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tankwagon(s)	2,500	2,500	2,500	5,000	11,500	27,500
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	2,800	4,800	8,900
Vacuum liquid manure tankwagon(s)	2,700	2,700	3,500	7,400	18,000	39,900
Injectors for vacuum liquid manure tankwagon(s)	1,300	1,300	1,500	3,100	6,300	12,900
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,378	2,582	3,092	10,092	13,312	17,824
Acres of land required for manure disposal	5	9	26	53	105	210

Table 29. Capital investment requirements for system 2 options with 500# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with deep pit storage	$22,989	$42,791	$115,340	$230,679	$461,358	$922,716
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tankwagon(s)	2,500	2,500	2,500	5,000	11,500	27,500
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	2,800	4,800	8,900
Acres of land required for manure disposal	18	37	110	220	440	880

Table 30. Capital investment requirements for system 3 options with 500# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with flushing gutter	$22,095	$32,074	$68,476	$136,951	$273,902	$547,804
Anaerobic lagoon	1,747	3,196	8,827	17,155	33,682	66,555
Manure pump(s)	2,800	2,800	2,800	5,600	8,400	14,000
Liquid manure tankwagon(s)	2,500	2,500	2,500	5,000	12,500	28,000
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	2,800	5,000	9.000
Vacuum liquid manure tankwagon(s)	2,700	2,700	3,500	8,700	18,300	40.800
Injectors for vacuum liquid manure tankwagon(s)	1,300	1,300	1,500	3,100	6,400	12,800
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	2,463	2,702	3,301	10,387	13,937	19,003
Acres of land required for manure disposal	6	12	36	72	144	289

Table 31. Capital investment requirements for systems 4 and 5 options with 500# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Open lot - no shelter	$6,279	$10,868	$31,400	$62,800	$125,601	$251,201
Open lot - windbreak fence	6,389	11,003	31,815	63,630	127,261	254,521
Open lot - open front shed	11,948	20,970	61,707	123,414	246,830	493,658
Open lot - open front shed and windbreak fence	12,172	21,302	62,721	125,442	250,884	501,727
Settling basin and detention lagoon	471	725	1,679	2,142	5,771	11,136
Manure pump(s)	2,800	2,800	2,800	2,800	2,800	2,800
Liquid manure tank-wagon(s)	2,500	2,500	2,500	2,500	2,500	2,500
Injectors for liquid manure tankwagon(s)	1,400	1,400	1,400	1,400	1,400	1,400
Vacuum liquid manure tankwagon(s)	2,700	2,700	2,700	2,700	2,700	3,000
Injectors for liquid manure tankwagon(s)	1,300	1,300	1,300	1,300	1,300	1,400

Irrigation system:						
Stationary big gun:						
100-1199 AU	2,275	2,436	2,839	9,735	10,294	11,085
Traveling big gun:						
1200-4800 AU						
Conventional manure spreader(s)	1,500	1,500	1,900	4,300	11,800	28,200
Manure loader(s)	1,600	1,600	2,000	2,000	6,000	14,000
Disc(s)	2,730	2,730	2,730	2,730	2,730	2,730
Acres of land required for manure disposal	12	24	71	141	282	565

Table 32. Capital investment requirements for system 6 options with 500# of N allowed per acre and 21 disposal days

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Confinement system with solid floor	$10,695	$19,404	$47,576	$95,151	$190,302	$380,604
Conventional manure spreader(s)	1,500	1,500	2,500	5,000	14,500	32,400
Manure loader(s)	1,600	1,600	2,000	2,000	6,000	14,000
Disc(s)	2,730	2,730	2,730	2,730	2,730	2,730
Acres of land required for manure disposal	18	36	108	217	433	867

Table 33. Annual costs of animal facilities and waste collection and storage facilities

Investment item	Design space: Animal units					
	100	200	600	1200	2400	4800
Cold confinement with oxidation ditch	$5,125	$9,370	$24,415	$48,506	$96,364	$191,433
Cold confinement with deep pit	4,138	7,702	20,761	41,522	83,044	166,089
Cold confinement with flushing gutter	3,977	5,887	12,326	24,651	49,302	98,605
Open lot with no shelter	1,130	1,956	5,652	11,304	22,608	45,216
Open lot with wind-break fence	1,150	1,981	5,727	11,453	22,907	45,814
Open lot with open front shed	2,151	3,775	11,107	22,215	44,429	88,858
Open lot with open front shed and wind-break fence	2,191	3,834	11,290	22,580	45,159	90,311
Cold confinement with solid floor	1,925	3,493	8,564	17,127	34,254	68,509
Anaerobic lagoon	314	575	1,589	3,088	6,063	11,980
Settling basin and detention lagoon	85	131	302	386	1,039	2,004

Table 34. Annual costs of waste handling and disposal options for system 1, with 250# of N allowed per acre and 14 disposal days

		100		200	
	System utilization %	Total cost $	Cost per head $	Total cost $	Cost per head $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.63
	70	344	4.91	639	4.54
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	727	14.54	969	9.69
	60	773	12.88	1062	8.85
	70	818	11.69	1156	8.26
	80	864	10.80	1250	7.81
	90	909	10.10	1343	7.46
	100	954	9.54	1437	7.19
Injectors for liquid manure tankwagon(s)	50	287	5.74	294	2.94
	60	288	4.80	297	2.48
	70	290	4.14	300	2.14
	80	291	3.64	302	1.89
	90	292	3.24	305	1.69
	100	294	2.94	308	1.54
Vacuum liquid manure tankwagon(s)	50	857	17.14	1193	11.93
	60	921	15.35	1323	11.02
	70	984	14.06	1454	10.38
	80	1048	13.10	1584	9.90
	90	1111	12.34	1715	9.53
	100	1175	11.75	1845	9.23
Injectors for vacuum liquid manure tankwagon(s)	50	269	5.38	279	2.79
	60	271	4.52	283	2.36
	70	273	3.90	286	2.04
	80	275	3.44	290	1.81
	90	277	3.08	294	1.63
	100	278	2.78	298	1.49
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	50	537	10.74	617	6.17
	60	543	9.05	628	5.23
	70	548	7.83	639	4.56
	80	554	6.93	651	4.07
	90	559	6.21	662	3.68
	100	565	5.65	674	3.37

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per head $	Total cost $	Cost per head $	Total cost $	Cost per head $	Total cost $	Cost per head $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2724	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.20	2763	1.15	4373	0.91
2552	8.51	4816	8.03	10538	8.78	22946	9.56
2858	7.94	5419	7.53	11838	8.22	25783	8.95
3164	7.53	6023	7.17	13138	7.82	28620	8.52
3471	7.23	6626	6.90	14437	7.52	31458	8.19
3777	6.99	7229	6.69	15737	7.28	34295	7.94
4083	6.81	7832	6.53	17037	7.10	37132	7.74
377	1.26	760	1.27	1561	1.30	3175	1.32
384	1.07	776	1.08	1594	1.11	3242	1.13
392	0.93	792	0.94	1626	0.97	3309	0.98
399	0.83	808	0.84	1658	0.83	3376	0.88
406	0.75	824	0.76	1690	0.78	3443	0.80
414	0.69	839	0.70	1723	0.72	3510	0.73
3170	10.57	7214	12.02	14878	12.40	31941	13.31
3588	9.97	8093	11.24	16678	11.58	35773	12.42
4006	9.54	8972	10.68	18477	11.00	39605	11.79
4424	9.22	9851	10.26	20277	10.56	43437	11.31
4842	8.97	10729	9.93	22077	10.22	47269	10.94
5260	8.77	11608	9.67	23876	9.95	51101	10.65
581	1.94	1050	1.75	2168	1.81	4475	1.86
593	1.65	1072	1.49	2214	1.54	4565	1.59
605	1.44	1094	1.30	2259	1.34	4660	1.39
617	1.29	1116	1.16	2305	1.20	4754	1.24
629	1.16	1138	1.05	2350	1.09	4848	1.12
641	1.07	1160	0.97	2396	1.00	4942	1.03
858	2.86	2942	4.90	4055	3.38	6524	2.72
896	2.49	3027	4.20	4204	2.92	6802	2.36
935	2.23	3113	3.71	4354	2.59	7081	2.11
973	2.03	3198	3.33	4506	2.35	7357	1.92
1011	1.87	3284	3.04	4656	2.16	7635	1.77
1049	1.75	3369	2.81	4805	2.00	8005	1.67

Table 35. Annual costs of waste handling and disposal options for system 2, with 250# of N allowed per acre and 14 disposal days

		100		200	
	System utilization %	Total cost $	Cost per head $	Total cost $	Cost per head $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.62
	70	344	4.91	639	4.56
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	745	14.90	1018	10.18
	60	794	13.23	1122	9.35
	70	843	12.04	1225	8.75
	80	892	11.15	1329	8.31
	90	941	10.46	1432	7.96
	100	990	9.90	1536	7.68
Manure injector(s)	50	288	5.76	295	2.95
	60	289	4.82	299	2.49
	70	290	4.14	302	2.16
	80	292	3.65	305	1.91
	90	293	3.25	308	1.71
	100	295	2.95	311	1.56

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per head $	Total cost $	Cost per head $	Total cost $	Cost per head $	Total cost $	Cost per head $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2724	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.20	2763	1.15	4373	0.91
2720	9.07	5274	8.79	11732	9.78	26547	11.06
3060	8.50	5969	8.29	13277	9.22	30052	10.43
3400	8.10	6664	7.93	14816	8.82	33558	9.99
3741	7.79	7359	7.67	16355	8.52	37063	9.65
4081	7.56	8054	7.46	17895	8.28	40568	9.39
4421	7.37	8749	7.29	19434	8.10	44074	9.18
381	1.27	772	1.29	1591	1.33	3550	1.48
389	1.08	790	1.10	1629	1.13	3637	1.26
397	0.94	809	0.96	1668	0.99	3723	1.11
405	0.84	827	0.86	1706	0.89	3809	0.99
414	0.77	845	0.78	1744	0.81	3895	0.90
422	0.70	864	0.72	1782	0.74	3981	0.83

Table 36. Annual costs of waste handling and disposal options for system 3 with 250# of N allowed per acre and 14 disposal days

	System utilization %	100 Total cost $	100 Cost per AU, $	200 Total cost $	200 Cost per AU, $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.62
	70	344	4.91	639	4.56
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	730	14.60	977	9.77
	60	776	12.93	1072	8.93
	70	822	11.74	1167	8.34
	80	868	10.85	1263	7.89
	90	914	10.16	1358	7.54
	100	960	9.60	1453	7.27
Injectors for liquid manure tankwagon(s)	50	287	5.74	294	2.94
	60	288	4.80	297	2.48
	70	290	4.14	300	2.14
	80	291	3.64	303	1.89
	90	292	3.24	306	1.70
	100	294	2.94	309	1.55
Vacuum liquid manure tankwagon(s)	50	861	17.22	1203	12.03
	60	925	15.42	1335	11.13
	70	990	14.14	1468	10.49
	80	1054	13.18	1601	10.01
	90	1118	12.42	1733	9.63
	100	1182	11.82	1866	9.33
Injectors for vacuum liquid manure tankwagon(s)	50	269	5.38	279	2.79
	60	271	4.52	283	2.36
	70	273	3.90	287	2.05
	80	275	3.44	291	1.82
	90	277	3.08	294	1.63
	100	279	2.79	298	1.49
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	50	566	11.32	658	6.58
	60	570	9.50	672	5.60
	70	576	8.23	684	4.89
	80	582	7.28	696	4.35
	90	590	6.56	710	3.94
	100	596	5.96	722	3.61

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2724	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.20	2763	1.15	4373	0.91
2580	8.60	5316	8.86	11157	9.30	23693	9.87
2891	8.03	5971	8.29	12532	8.70	26664	9.26
3203	7.63	6626	7.89	13907	8.28	29634	8.82
3515	7.32	7281	7.58	15282	7.96	32605	8.49
3827	7.09	7936	7.35	16658	7.71	35576	8.23
4139	6.90	8591	7.16	10833	7.51	38546	8.03
377	1.26	759	1.27	1563	1.30	3443	1.43
385	1.07	774	1.08	1596	1.11	3516	1.22
392	0.93	790	0.94	1629	0.97	3588	1.07
400	0.83	806	0.84	1661	0.87	3661	0.95
407	0.75	822	0.76	1694	0.78	3734	0.86
415	0.69	837	0.70	1727	0.72	3806	0.79
3181	10.60	6694	11.16	15018	12.52	33674	14.03
3589	9.97	7509	10.43	16830	11.69	37673	13.08
3997	9.52	8324	9.91	18641	11.10	41671	12.40
4405	9.18	9138	9.52	20453	10.65	45670	11.89
4813	8.91	9953	9.22	22264	10.31	49669	11.50
5221	8.70	10768	8.97	24076	10.03	53668	11.18
600	2.00	1072	1.79	2168	1.81	4556	1.90
612	1.70	1095	1.52	2236	1.55	4652	1.62
624	1.49	1117	1.33	2282	1.36	4747	1.41
636	1.33	1140	1.19	2329	1.21	4842	1.26
648	1.20	1162	1.08	2375	1.10	4937	1.14
660	1.10	1185	0.99	2421	1.01	5033	1.05
940	3.13	3083	5.14	4333	3.61	7122	2.97
986	2.74	3175	4.41	4494	3.12	7215	2.51
1029	2.45	3264	3.89	4655	2.77	7732	2.30
1072	2.23	3356	3.50	4819	2.51	8039	2.09
1117	2.07	3445	3.19	4980	2.31	8343	1.93
1160	1.93	3537	2.94	5142	2.14	8649	1.80

Table 37. Annual costs of waste handling and disposal options for system 4, with 250# of N allowed per acre and 14 disposal days

	System utilization, %	100 Total cost $	100 Cost per AU, $	200 Total cost $	200 Cost per AU, $
	50	85	1.70	131	1.31
	60	85	1.42	131	1.09
Settling basin and	70	85	1.21	131	0.94
detention lagoon	80	85	1.06	131	0.81
	90	85	0.94	131	0.73
	100	85	0.85	131	0.66
	50	260	5.20	470	4.70
	60	260	4.33	470	3.92
Manure pump(s)	70	260	3.71	470	3.36
	80	260	3.25	470	2.94
	90	260	2.89	470	2.61
	100	260	2.60	470	2.35
	50	580	11.60	646	6.46
	60	580	9.67	646	5.38
Liquid manure	70	580	8.29	646	4.61
tankwagon(s)	80	580	7.25	646	4.04
	90	580	6.44	646	3.59
	100	580	5.80	646	3.23
	50	282	5.64	284	2.84
	60	282	4.70	284	2.37
Injectors for liquid	70	282	4.03	284	2.03
manure tankwagon(s)	80	282	3.53	284	1.78
	90	282	3.13	284	1.58
	100	282	2.82	284	1.42
	50	651	13.02	744	7.44
	60	651	10.85	744	6.20
Vacuum liquid	70	651	9.30	744	5.31
manure tankwagon(s)	80	651	8.14	744	4.65
	90	651	7.23	744	4.13
	100	651	6.51	744	3.72
	50	263	5.26	266	2.66
	60	263	4.38	266	2.22
Injectors for vacuum	70	263	3.76	266	1.90
liquid manure	80	263	3.29	266	1.66
tankwagon(s)	90	263	2.92	266	1.48
	100	263	2.63	266	1.33
	50	533	10.66	631	6.31
Irrigation system:	60	533	8.88	631	5.26
Stationary big gun:	70	533	7.61	631	4.51
100-1199 AU	80	533	6.66	631	3.94
Traveling big gun:	90	533	5.92	631	3.51
1200-4800 AU	100	533	5.33	631	3.16

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
302	1.01	386	0.64	1039	0.87	2004	0.84
302	0.84	386	0.54	1039	0.72	2004	0.69
302	0.72	386	0.46	1039	0.62	2004	0.60
302	0.63	386	0.40	1039	0.54	2004	0.52
302	0.56	386	0.36	1039	0.48	2004	0.46
302	0.50	386	0.32	1039	0.43	2004	0.42
1311	4.44	1368	2.28	1482	1.24	2311	0.96
1311	3.64	1368	1.90	1482	1.02	2311	0.80
1311	3.12	1368	1.63	1482	0.88	2311	0.69
1311	2.73	1368	1.43	1482	0.77	2311	0.60
1311	2.43	1368	1.27	1482	0.69	2311	0.53
1311	2.19	1368	1.14	1482	0.62	2311	0.48
925	3.08	1089	1.82	2328	1.94	4981	2.07
925	2.57	1089	1.52	2328	1.62	4981	1.73
925	2.20	1089	1.30	2328	1.39	4981	1.48
925	1.93	1089	1.13	2328	1.21	4981	1.30
925	1.71	1089	1.01	2328	1.08	4981	1.15
925	1.54	1089	0.91	2328	0.97	4981	1.04
293	0.98	298	0.50	335	0.28	458	0.19
293	0.81	298	0.41	335	0.23	458	0.16
293	0.70	298	0.35	335	0.20	458	0.14
293	0.61	298	0.31	335	0.17	458	0.12
293	0.54	298	0.28	335	0.16	458	0.11
293	0.49	298	0.25	335	0.14	458	0.10
1130	3.77	1354	2.26	3114	2.59	5982	2.49
1130	3.14	1354	1.88	3114	2.16	5982	2.08
1130	2.69	1354	1.61	3114	1.85	5982	1.78
1130	2.35	1354	1.41	3114	1.62	5982	1.56
1130	2.09	1354	1.25	3114	1.44	5982	1.38
1130	1.88	1354	1.13	3114	1.30	5982	1.25
277	0.92	284	0.47	353	0.29	683	0.28
277	0.77	284	0.39	353	0.24	683	0.24
277	0.66	284	0.34	353	0.21	683	0.20
277	0.58	284	0.30	353	0.18	683	0.18
277	0.51	284	0.26	353	0.16	683	0.16
277	0.46	284	0.24	353	0.15	683	0.14
956	3.19	2295	3.83	2841	2.37	3753	1.56
956	2.66	2295	3.19	2841	1.97	3753	1.30
956	2.28	2295	2.73	2841	1.69	3753	1.12
956	1.99	2295	2.39	2841	1.48	3753	0.98
956	1.77	2295	2.13	2851	1.31	3753	0.87
956	1.59	2295	1.91	2841	1.18	3753	0.78

Table 38. Annual costs of waste handling and disposal options for system 5, with 250# of N allowed per acre and 14 disposal days

		100		200	
	System utilization, %	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
Conventional manure spreader(s)	50	582	11.64	876	8.76
	60	638	10.63	991	8.26
	70	695	9.93	1106	7.90
	80	751	9.39	1221	7.63
	90	808	.898	1336	7.42
	100	864	8.64	1452	7.26
Manure loader(s)	50	592	11.84	867	8.67
	60	645	10.75	973	8.11
	70	698	9.97	1079	7.71
	80	751	9.39	1183	7.39
	90	804	8.93	1288	7.16
	100	856	8.56	1392	6.96
Disc(s)	50	562	11.24	577	5.77
	60	565	9.42	584	4.87
	70	568	8.11	590	4.21
	80	571	7.14	596	3.73
	90	574	6.37	603	3.35
	100	577	5.77	609	3.04

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
2415	8.05	6176	10.29	14190	11.83	31082	12.95
2778	7.72	7092	9.85	16224	11.27	35499	12.33
3141	7.48	8007	9.53	18258	10.87	39916	11.88
3504	7.30	8922	9.29	20292	10.57	44332	11.54
3867	7.16	9838	9.11	22326	10.34	48749	11.28
4230	7.05	10753	8.96	24360	10.15	53165	11.08
2010	6.70	3864	6.44	9576	7.98	25704	10.71
2304	6.40	4435	6.16	11117	7.72	30154	10.47
2591	6.17	5006	5.96	12650	7.53	34574	10.29
2870	5.98	5558	5.79	14189	7.39	38938	10.14
3154	5.84	6124	5.67	15746	7.29	43373	10.04
3432	5.72	6672	5.56	17280	7.20	47808	9.96
640	2.13	735	1.23	923	0.77	1300	0.54
659	1.83	772	1.07	999	0.69	1451	0.50
678	1.61	810	0.96	1074	0.64	1602	0.48
697	1.45	848	0.88	1149	0.60	1753	0.46
716	1.33	885	0.92	1225	0.57	1904	0.44
735	1.23	923	0.77	1300	0.54	2109	0.44

Table 39. Annual costs of waste handling and disposal options for system 6, with 250# of N allowed per acre and 14 disposal days

		100		200	
	System utilization %	Total cost $	Cost per AU $	Total cost $	Cost per AU $
Conventional manure spreader(s)	50	597	11.94	918	9.18
	60	656	10.93	1041	8.68
	70	716	10.23	1165	8.32
	80	775	9.69	1288	8.05
	90	834	9.27	1412	7.84
	100	894	8.94	1535	7.68
Manure loader(s)	50	596	11.92	878	8.78
	60	649	10.81	982	8.18
	70	701	10.01	1087	7.76
	80	753	9.41	1190	7.44
	90	805	8.94	1291	7.17
	100	856	8.56	1396	6.98
Disc(s)	50	577	11.54	609	6.09
	60	584	9.73	621	5.18
	70	590	8.43	634	4.53
	80	596	7.45	647	4.03
	90	603	6.70	659	3.66
	100	609	6.09	672	3.36

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
2633	8.78	7605	12.67	16413	13.68	36994	15.41
3039	8.44	8726	12.12	18736	13.01	42209	14.66
3446	8.20	9847	11.72	21059	12.54	47423	14.11
3852	8.03	10969	11.43	23382	12.18	52638	13.71
4259	7.89	12090	11.19	25704	11.90	57853	13.39
4666	7.78	13211	11.01	28027	11.68	63068	13.14
2051	6.83	3924	6.54	10416	8.68	26880	11.20
2351	6.53	4507	6.26	12125	8.42	31565	10.96
2646	6.30	5083	6.05	13826	8.23	36221	10.78
2935	6.11	5648	5.88	15514	8.08	40781	10.62
3219	5.96	6205	5.75	17215	7.97	45446	10.52
3499	5.83	6755	5.63	18881	7.87	50079	10.43
735	2.45	923	1.54	1300	1.08	2310	0.96
772	2.14	999	1.39	1451	1.01	2684	0.93
810	1.93	1074	1.28	1602	0.95	2809	0.84
848	1.77	1149	1.20	1753	0.91	3127	0.81
885	1.64	1225	1.13	1904	0.88	3414	0.79
923	1.54	1300	1.08	2055	0.85	3655	0.76

Table 40. Annual costs of waste handling and disposal options for system 1 with 250# of N allowed per acre with 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
Manure pump(s)	50	260	5.20	470	4.73
	60	302	5.03	555	4.63
	70	344	4.91	639	4.54
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	727	14.54	969	9.69
	60	773	12.88	1062	8.85
	70	818	11.69	1156	8.26
	80	864	10.80	1250	7.81
	90	909	10.10	1343	7.46
	100	954	9.54	1437	7.19
Injectors for liquid manure tankwagon(s)	50	287	5.74	294	2.94
	60	288	4.80	297	2.48
	70	290	4.14	300	2.14
	80	291	3.64	302	1.89
	90	292	3.24	305	1.69
	100	294	2.94	308	1.54
Vacuum liquid manure tankwagon(s)	50	857	17.14	1193	11.93
	60	921	15.35	1323	11.02
	70	984	14.06	1454	10.38
	80	1048	13.10	1584	9.90
	90	1111	12.34	1715	9.53
	100	1175	11.75	1845	9.23
Injectors for vacuum liquid manure tankwagon(s)	50	269	5.38	279	2.79
	60	271	4.52	283	2.36
	70	273	3.90	286	2.04
	80	275	3.44	290	1.81
	90	277	3.08	294	1.63
	100	278	2.78	298	1.49
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	50	537	10.74	617	6.17
	60	543	9.05	628	5.23
	70	548	7.83	639	4.56
	80	554	6.93	651	4.07
	90	559	6.21	662	3.68
	100	565	5.65	674	3.37

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1850	1.54	2311	0.96
1564	4.34	1622	2.25	2190	1.52	2724	0.95
1816	4.32	1875	2.23	2530	1.51	3136	0.93
2068	4.31	2129	2.22	2870	1.49	3548	0.92
2320	4.30	2383	2.21	3210	1.48	3960	0.92
2573	4.29	2636	2.20	3550	1.48	4373	0.91
2009	6.70	4222	7.04	8799	7.33	19808	8.26
2311	6.42	4866	6.76	10063	6.99	22638	7.86
2613	6.22	5510	6.56	11326	6.74	25467	7.58
2915	6.07	6155	6.41	12590	6.56	28297	7.37
3217	5.96	6799	6.30	13854	6.41	31127	7.21
3518	5.86	7743	6.20	15118	6.30	33956	7.07
325	1.08	656	1.09	1175	0.98	2396	1.00
334	0.93	676	0.94	1209	0.84	2467	0.86
343	0.82	694	0.83	1245	0.74	2538	0.76
352	0.73	714	0.74	1280	0.67	2610	0.68
361	0.67	733	0.68	1315	0.61	2681	0.62
370	0.62	753	0.63	1350	0.56	2752	0.57
2570	8.57	5944	9.91	12361	10.30	27246	11.35
2929	8.14	6765	9.40	14082	9.78	31015	10.77
3287	7.83	7586	9.03	15802	9.41	34784	10.35
3645	7.59	8407	8.76	17522	9.13	38553	10.04
4003	7.41	9228	8.54	19242	8.91	42322	9.80
4361	7.27	10049	8.37	20963	8.73	46091	9.60
375	1.25	748	1.25	1528	1.27	3154	1.31
385	1.07	670	0.93	1574	1.09	3248	1.13
396	0.94	792	0.94	1619	0.96	3343	0.99
407	0.85	813	0.85	1665	0.87	3438	0.90
418	0.77	835	0.77	1710	0.79	3533	0.82
429	0.72	856	0.71	1756	0.73	3627	0.76
858	2.86	2603	4.34	3570	2.98	5237	2.18
896	2.49	2742	3.81	3758	2.61	5581	1.94
935	2.23	2879	3.43	3946	2.35	5921	1.76
973	2.03	3018	3.14	4133	2.15	6266	1.63
1011	1.87	3157	2.92	4321	2.00	6605	1.53
1049	1.75	3297	2.74	4508	1.88	6949	1.45

Table 41. Annual costs of waste handling and disposal options for system 2 with 250# of N allowed per acre with 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.62
	70	344	4.91	639	4.56
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	745	14.90	1018	10.18
	60	794	13.23	1122	9.35
	70	843	12.04	1225	8.75
	80	892	11.15	1329	8.31
	90	941	10.46	1432	7.96
	100	990	9.90	1536	7.68
Manure injectors	50	288	5.76	295	2.95
	60	289	4.82	299	2.49
	70	290	4.14	302	2.16
	80	292	3.65	305	1.91
	90	293	3.25	308	1.71
	100	295	2.95	311	1.56

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2734	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.22	2763	1.15	4373	0.91
2266	7.55	4814	8.02	10794	9.00	23706	9.88
2619	7.28	5541	7.70	12424	8.63	27227	9.45
2972	7.08	6268	7.46	14055	8.37	30749	9.15
3325	6.93	6995	7.29	15686	8.17	34270	8.92
3679	6.81	7722	7.15	17317	8.02	37791	8.75
4032	6.72	8449	7.04	18947	7.89	41312	8.61
333	1.11	710	1.18	1186	0.99	2506	1.04
343	0.95	732	1.02	1227	0.85	2591	0.90
354	0.84	754	0.90	1268	0.75	2676	0.80
364	0.76	777	0.81	1309	0.68	2761	0.72
375	0.69	798	0.74	1350	0.63	2847	0.66
386	0.64	821	0.68	1391	0.58	2932	0.61

Table 42. Annual costs of waste handling and disposal options for system 3 with 250# of N allowed per acre and 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.62
	70	344	4.91	639	4.56
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	730	14.60	977	9.77
	60	776	12.93	1072	8.93
	70	822	11.74	1167	8.34
	80	868	10.85	1263	7.89
	90	914	10.16	1358	7.54
	100	960	9.60	1453	7.27
Injectors for liquid manure tankwagon(s)	50	287	5.74	294	2.94
	60	288	4.80	297	2.48
	70	290	4.14	300	2.14
	80	291	3.64	303	1.89
	90	292	3.24	306	1.70
	100	294	2.94	309	1.55
Vacuum liquid manure tankwagon(s)	50	861	17.22	1203	12.03
	60	925	15.42	1335	11.13
	70	990	14.14	1468	10.49
	80	1054	13.18	1601	10.01
	90	1118	12.42	1733	9.63
	100	1182	11.82	1866	9.33
Injectors for vacuum liquid manure	50	269	5.38	279	2.79
	60	271	4.52	283	2.36
	70	273	3.90	287	2.05
	80	275	3.44	291	1.82
	90	277	3.08	294	1.63
	100	279	2.79	298	1.49
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	50	566	11.32	658	6.58
	60	570	9.50	672	5.60
	70	576	8.23	684	4.89
	80	582	7.28	696	4.35
	90	590	6.56	710	3.94
	100	596	5.96	722	3.61

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2734	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.22	2763	1.15	4373	0.91
2052	6.84	4299	7.17	9640	8.03	20319	8.47
2362	6.56	4923	6.84	11020	7.65	23215	8.06
2672	6.36	5547	6.60	12400	7.38	26111	7.77
2983	6.21	6171	6.43	13780	7.18	29007	7.55
3293	6.10	6790	6.29	15160	7.02	31903	7.38
3603	6.01	7419	6.18	16540	6.89	34799	7.25
326	1.09	695	1.16	1172	0.98	2447	1.02
336	0.93	714	0.99	1207	0.84	2520	0.88
345	0.82	733	0.87	1241	0.74	2594	0.77
354	0.74	751	0.78	1276	0.66	2667	0.69
364	0.67	770	0.71	1310	0.61	2740	0.63
373	0.62	789	0.66	1345	0.56	2814	0.59
2602	8.67	6033	10.06	13259	11.05	29114	12.13
2967	8.24	6872	9.54	15087	10.48	33113	11.50
3331	7.93	7711	9.18	16915	10.07	37111	11.04
3695	7.70	8549	8.91	18742	9.76	41110	10.71
4060	7.52	9388	8.69	20570	9.52	45109	10.44
4424	7.37	10227	8.52	22398	9.33	49108	10.23
376	1.25	751	1.24	1548	1.29	3196	1.33
387	1.08	773	1.07	1594	1.11	3292	1.14
398	0.95	795	0.95	1640	0.98	3387	1.01
409	0.85	817	0.85	1686	0.88	3482	0.91
420	0.78	839	0.78	1731	0.80	3577	0.83
431	0.72	861	0.72	1777	0.74	3673	0.77
940	3.13	2710	4.52	3792	3.16	6376	2.66
986	2.74	2854	3.96	3993	2.77	6705	2.33
1029	2.45	2998	3.57	4194	2.50	7036	2.09
1072	2.23	3142	3.27	4394	2.29	7365	1.92
1117	2.07	3286	3.04	4594	2.13	7696	1.78
1160	1.93	3432	2.86	4795	2.00	8028	1.67

Table 43. Annual costs of waste handling and disposal options for system 4, with 250# of N allowed per acre and 21 disposal days

	System utilization, %	100 Total cost $	100 Cost per AU, $	200 Total cost $	200 Cost per AU, $
	50	85	1.70	131	1.31
	60	85	1.42	131	1.09
Settling basin and	70	85	1.21	131	0.94
detention lagoon	80	85	1.06	131	0.81
	90	85	0.94	131	0.73
	100	85	0.85	131	0.66
	50	260	5.20	470	4.70
	60	260	4.33	470	3.92
Manure pump(s)	70	260	3.71	470	3.36
	80	260	3.25	470	2.94
	90	260	2.89	470	2.61
	100	260	2.60	470	2.35
	50	579	11.58	646	6.46
	60	579	9.65	646	5.38
Liquid manure	70	579	8.27	646	4.61
tankwagon(s)	80	579	7.24	646	4.04
	90	579	6.43	646	3.59
	100	579	5.79	646	3.23
	50	282	5.64	284	2.84
	60	282	4.70	284	2.37
Injectors for liquid	70	282	4.03	284	2.03
manure tankwagon(s)	80	282	3.53	284	1.78
	90	282	3.13	284	1.58
	100	282	2.82	284	1.42
	50	651	13.02	744	7.44
	60	651	10.85	744	6.20
Vacuum liquid	70	651	9.30	744	5.31
manure tankwagon(s)	80	651	8.14	744	4.65
	90	651	7.23	744	4.13
	100	651	6.51	744	3.72
	50	263	5.26	266	2.66
	60	263	4.38	266	2.22
Injectors for vacuum	70	263	3.76	266	1.90
liquid manure	80	263	3.29	266	1.66
tankwagon(s)	90	263	2.92	266	1.48
	100	263	2.63	266	1.33
	50	533	10.66	631	6.31
Irrigation system:	60	533	8.88	631	5.26
Stationary big gun:	70	533	7.61	631	4.51
100-1199 AU	80	533	6.66	631	3.94
Traveling big gun:	90	533	5.92	631	3.51
1200-4800 AU	100	533	5.33	631	3.16

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
302	1.01	386	0.64	1039	0.87	2004	0.84
302	0.84	386	0.54	1039	0.72	2004	0.69
302	0.72	386	0.46	1039	0.62	2004	0.60
302	0.63	386	0.40	1039	0.54	2004	0.52
302	0.56	386	0.36	1039	0.48	2004	0.46
302	0.50	386	0.32	1039	0.43	2004	0.42
1311	4.44	1368	2.28	1482	1.24	2311	0.96
1311	3.64	1368	1.90	1482	1.03	2311	0.80
1311	3.12	1368	1.63	1482	0.88	2311	0.69
1311	2.73	1368	1.43	1482	0.77	2311	0.60
1311	2.43	1368	1.27	1482	0.69	2311	0.53
1311	2.19	1368	1.14	1482	0.62	2311	0.48
925	3.08	1089	1.82	2328	1.94	4462	1.86
925	2.57	1089	1.52	2328	1.62	4462	1.55
925	2.20	1089	1.30	2328	1.39	4462	1.33
925	1.93	1089	1.13	2328	1.21	4462	1.16
925	1.71	1089	1.01	2328	1.08	4462	1.03
925	1.54	1089	0.91	2328	0.97	4462	0.93
293	0.98	298	0.50	335	0.28	398	0.17
293	0.81	298	0.41	335	0.23	398	0.14
293	0.70	298	0.35	335	0.20	398	0.12
293	0.61	298	0.31	335	0.17	398	0.10
293	0.54	298	0.28	335	0.16	398	0.09
293	0.49	298	0.25	335	0.14	398	0.08
1130	3.77	1354	2.26	3114	2.59	5490	2.29
1130	3.14	1354	1.88	3114	2.16	5490	1.91
1130	2.69	1354	1.61	3114	1.85	5490	1.63
1130	2.35	1354	1.41	3114	1.62	5490	1.43
1130	2.09	1354	1.25	3114	1.44	5490	1.27
1130	1.88	1354	1.13	3114	1.30	5490	1.14
277	0.92	284	0.47	353	0.29	456	0.19
277	0.77	284	0.39	353	0.24	456	0.16
277	0.66	284	0.34	353	0.21	456	0.14
277	0.58	284	0.30	353	0.18	456	0.12
277	0.51	284	0.26	353	0.16	456	0.11
277	0.46	284	0.24	353	0.15	456	0.10
956	3.19	2295	3.83	2841	2.37	3753	1.56
956	2.66	2295	3.19	2841	1.97	3753	1.30
956	2.28	2295	2.73	2841	1.69	3753	1.12
956	1.99	2295	2.39	2841	1.48	3753	0.98
956	1.77	2295	2.13	2841	1.31	3753	0.87
956	1.59	2295	1.91	2841	1.18	3753	0.78

Table 44. Annual costs of waste handling and disposal options for system 5 with 250# of N allowed per acre and 21 disposal days

		100		200	
	System utilization %	Total cost $	Cost per AU $	Total cost $	Cost per AU $
Conventional manure spreader(s)	50	582	11.64	876	8.76
	60	638	10.63	991	8.26
	70	695	9.93	1106	7.90
	80	751	9.39	1221	7.63
	90	808	8.98	1336	7.42
	100	864	8.64	1452	7.26
Manure loader(s)	50	592	11.84	867	8.67
	60	645	10.75	973	8.11
	70	698	9.97	1079	7.71
	80	751	9.39	1183	7.39
	90	804	8.93	1288	7.16
	100	856	8.56	1392	6.96
Disc(s)	50	562	11.24	577	5.77
	60	565	9.42	584	4.87
	70	568	8.11	590	4.21
	80	571	7.14	596	3.73
	90	574	6.37	603	3.35
	100	577	5.77	609	3.04

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
2490	8.30	5897	9.83	12434	10.36	27668	11.53
2908	8.08	6837	9.50	14429	10.02	32042	11.13
3326	7.92	7776	9.26	16423	9.78	36415	10.83
3744	7.80	8716	9.08	18418	9.59	40789	10.62
4162	7.71	9655	8.94	20413	9.45	45162	10.45
4580	7.63	10595	8.83	22408	9.34	49536	10.32
1839	6.13	3249	5.42	7236	6.03	20112	8.38
2117	5.88	3793	5.27	8461	5.88	23443	8.14
2392	5.70	4332	5.16	9662	5.75	26746	7.96
2666	5.55	4866	5.07	10849	5.65	30732	7.80
2937	5.44	5395	5.00	12022	5.57	33178	7.68
3207	5.35	5920	4.93	13272	5.53	36384	7.58
640	2.13	735	1.23	923	0.77	1300	0.54
659	1.83	772	1.07	999	0.69	1451	0.50
678	1.61	810	0.96	1074	0.64	1602	0.48
697	1.45	848	0.83	1149	0.60	1753	0.46
716	1.33	885	0.82	1225	0.57	1904	0.44
735	1.23	923	0.77	1300	0.54	2055	0.43

Table 45. Annual costs of waste handling and disposal options for system 6 with 250# of N allowed per acre and 21 disposal days

		100		200	
	System utilization %	Total cost $	Cost per AU $	Total cost $	Cost per AU $
Conventional manure spreader(s)	50	597	11.94	918	9.18
	60	656	10.93	1041	8.68
	70	716	10.23	1165	8.32
	80	775	9.69	1288	8.05
	90	834	9.27	1412	7.84
	100	894	8.94	1535	7.68
Manure loader(s)	50	596	11.92	878	8.78
	60	649	10.81	982	8.18
	70	701	10.01	1087	7.76
	80	753	9.41	1190	7.44
	90	805	8.94	1291	7.17
	100	856	8.56	1392	6.96
Disc(s)	50	577	11.54	608	6.09
	60	584	9.73	621	5.18
	70	590	8.43	634	4.53
	80	596	7.45	647	4.03
	90	603	6.70	659	3.66
	100	609	6.09	672	3.36

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
3120	10.40	6958	11.60	14521	12.10	32890	13.70
3644	10.12	8082	11.23	16801	11.67	38052	13.21
4168	9.92	9205	10.96	19081	11.36	43213	12.86
4692	9.78	10329	10.76	21362	11.13	48375	12.60
5216	9.66	11452	10.60	23642	10.95	53537	12.39
5740	9.57	12576	10.48	25922	10.80	58699	12.23
1811	6.04	3184	5.31	7654	6.38	21096	8.79
2077	5.77	3703	5.14	8877	6.16	24594	8.54
2340	5.57	4213	5.02	10069	5.99	28056	8.35
2599	5.41	4716	4.91	11236	5.85	31449	8.19
2856	5.29	5212	4.83	12506	5.79	34906	8.08
3109	5.18	5702	4.75	13800	5.75	38304	7.98
735	2.45	923	1.54	1300	1.08	2448	1.02
772	2.14	999	1.39	1451	1.01	2852	0.99
810	1.93	1074	1.28	1602	0.95	3091	0.92
848	1.77	1149	1.20	1753	0.91	3379	0.88
885	1.64	1224	1.13	1904	0.88	3672	0.85
923	1.54	1300	1.08	2055	0.85	4032	0.84

Table 46. Annual costs of waste handling and disposal options for system 1 with 500# of N allowed per acre and 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.63
	70	344	4.91	639	4.54
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	722	14.44	954	9.54
	60	767	12.78	1046	8.72
	70	811	11.59	1137	8.12
	80	856	10.70	1228	7.68
	90	900	10.00	1318	7.32
	100	945	9.45	1409	7.05
Injectors for liquid manure tankwagon(s)	50	287	5.74	294	2.94
	60	288	4.80	296	2.47
	70	289	4.13	299	2.14
	80	290	3.63	302	1.89
	90	292	3.24	304	1.69
	100	293	2.93	307	1.54
Vacuum liquid manure tankwagon(s)	50	851	17.02	1175	11.75
	60	913	15.22	1302	10.85
	70	976	13.94	1429	10.21
	80	1038	12.98	1556	9.73
	90	1100	12.22	1683	9.35
	100	1162	11.62	1810	9.05
Injectors for vacuum liquid manure	50	269	5.38	278	2.78
	60	271	4.52	282	2.35
	70	273	3.90	286	2.04
	80	274	3.43	289	1.81
	90	276	3.07	293	1.63
	100	278	2.78	297	1.49
Irrigation system: Stationary big gun: 100-1199 AU Traveling big gun: 1200-4800 AU	50	490	9.80	548	5.48
	60	495	8.25	559	4.66
	70	501	7.16	567	4.05
	80	506	6.33	578	3.61
	90	510	5.67	550	3.06
	100	513	5.13	593	2.97

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1850	1.54	2311	0.96
1564	4.34	1622	2.25	2190	1.52	2724	0.95
1816	4.32	1875	2.23	2530	1.51	3136	0.93
2068	4.31	2129	2.22	2870	1.49	3548	0.92
2320	4.30	2383	2.21	3210	1.49	3960	0.92
2573	4.29	2636	2.20	3550	1.48	4373	0.91
1937	6.46	4018	6.70	8437	7.03	18741	7.81
2224	6.18	4622	6.42	9664	6.71	21389	7.43
2512	5.98	5226	6.22	10891	6.48	24038	7.15
2800	5.84	5830	6.07	12119	6.31	26686	6.95
3087	5.72	6433	5.96	13346	6.18	29334	6.79
3375	5.63	7037	5.86	14573	6.07	31982	6.66
323	1.08	650	1.08	1128	0.94	2092	0.87
332	0.92	668	0.93	1161	0.81	2155	0.75
340	0.81	686	0.82	1195	0.71	2217	0.66
349	0.73	704	0.73	1229	0.64	2280	0.59
357	0.66	722	0.67	1262	0.58	2342	0.54
366	0.61	741	0.62	1296	0.54	2405	0.50
2441	8.14	5070	8.45	12060	10.05	26240	10.93
2789	7.75	5788	8.04	13753	9.55	29892	10.38
3137	7.47	6506	7.75	15445	9.19	33544	9.98
3485	7.26	7224	7.53	17137	8.93	37196	9.69
3833	7.10	7942	7.35	18829	8.72	40848	9.46
4181	6.97	8660	7.21	20521	8.55	44500	9.27
352	1.17	729	1.22	1482	1.24	3033	1.26
363	1.01	750	1.04	1526	1.06	3123	1.08
373	0.89	772	0.92	1571	0.94	3214	0.95
384	0.80	794	0.83	1615	0.84	3304	0.86
394	0.73	815	0.75	1660	0.77	3395	0.79
405	0.68	837	0.70	1704	0.71	3485	0.73
723	2.41	2428	4.05	3197	2.66	4502	1.88
755	2.10	2557	3.55	3365	2.34	4795	1.66
785	1.87	2685	3.20	3530	2.10	5088	1.51
817	1.70	2814	2.93	3698	1.93	5381	1.40
846	1.57	2942	2.72	3866	1.79	5674	1.31
876	1.46	3071	2.56	4034	1.68	5964	1.24

Table 47. Annual costs of waste handling and disposal options for system 2 with 500# of N allowed per acre and 21 disposal days

		100		200	
	System utilization %	Total cost $	Cost per AU $	Total cost $	Cost per AU $
Manure pump(s)	50	260	5.20	470	4.70
	60	302	5.03	555	4.63
	70	344	4.91	639	4.54
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
Liquid manure tankwagon(s)	50	735	14.70	990	9.90
	60	782	13.03	1088	9.07
	70	829	11.84	1185	8.46
	80	876	10.95	1283	8.02
	90	923	10.26	1381	7.67
	100	970	9.70	1479	7.40
Manure injectors	50	287	5.74	295	2.95
	60	288	4.80	298	2.48
	70	290	4.14	300	2.14
	80	291	3.64	303	1.89
	90	293	3.26	306	1.70
	100	294	2.94	309	1.55

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1850	1.54	2311	0.96
1564	4.34	1622	2.25	2190	1.52	2724	0.95
1816	4.32	1875	2.23	2530	1.51	3136	0.93
2068	4.31	2129	2.22	2870	1.49	3548	0.92
2320	4.30	2383	2.21	3210	1.49	3960	0.92
2573	4.29	2636	2.20	3550	1.48	4373	0.91
2119	7.06	4532	7.55	9478	7.90	21062	8.78
2443	6.79	5238	7.28	10914	7.58	24174	8.39
2766	6.59	5944	7.08	12350	7.35	27287	8.12
3090	6.44	6651	6.93	13785	7.18	30399	7.92
3414	6.32	7357	6.81	15221	7.05	33511	7.76
3738	6.23	8063	6.72	16657	6.94	33624	7.01
328	1.09	650	1.08	1128	0.94	2092	0.87
338	0.94	668	0.93	1161	0.81	2155	0.75
348	0.83	686	0.82	1195	0.71	2217	0.66
357	0.74	704	0.73	1229	0.64	2280	0.59
367	0.68	722	0.67	1262	0.58	2342	0.54
377	0.63	741	0.62	1296	0.54	2405	0.50

Table 48. Annual costs of waste handling and disposal options for system 3 with 500# of N allowed per acre and 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
	50	260	5.20	470	4.70
	60	302	5.03	555	4.62
Manure pump(s)	70	344	4.91	639	4.56
	80	386	4.83	723	4.52
	90	428	4.76	807	4.48
	100	470	4.70	891	4.46
	50	724	14.48	960	9.60
	60	769	12.82	1053	8.78
Liquid manure	70	814	11.63	1145	8.18
tankwagon(s)	80	859	10.74	1237	7.73
	90	904	10.04	1329	7.38
	100	949	9.49	1421	7.10
	50	287	5.74	294	2.94
	60	288	4.80	297	2.48
Injectors for liquid	70	289	4.13	299	2.14
manure tankwagon(s)	80	291	3.64	302	1.89
	90	292	3.24	305	1.69
	100	293	2.93	308	1.54
	50	854	17.08	1182	11.82
	60	917	15.28	1311	10.93
Vacuum liquid	70	979	13.99	1439	10.28
manure tankwagon(s)	80	1042	13.03	1568	9.80
	90	1105	12.28	1696	9.42
	100	1168	11.68	1824	9.12
	50	269	5.38	279	2.79
	60	271	4.52	282	2.35
Injectors for vacuum	70	273	3.90	286	2.04
liquid manure	80	275	3.44	290	1.81
tankwagon(s)	90	276	3.07	294	1.63
	100	278	2.78	297	1.49
	50	510	10.20	576	5.76
Irrigation system:	60	516	8.60	587	4.89
Stationary big gun:	70	521	7.44	598	4.27
100-1199 AU	80	524	6.55	606	3.79
Traveling big gun:	90	529	5.88	617	3.43
	100	534	5.34	628	3.14

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
1311	4.37	1368	2.28	1482	1.24	2311	0.96
1564	4.34	1622	2.25	1738	1.21	2734	0.95
1816	4.32	1875	2.23	1994	1.19	3136	0.93
2068	4.31	2129	2.22	2251	1.17	3548	0.92
2320	4.30	2383	2.21	2507	1.16	3960	0.92
2573	4.29	2636	2.22	2763	1.15	4373	0.91
1967	6.56	4103	6.84	8575	7.15	19143	7.98
2261	6.28	4724	6.56	9795	6.80	21851	7.59
2554	6.08	5344	6.36	11014	6.56	24560	7.31
2848	5.93	5965	6.21	12233	6.37	27269	7.10
3141	5.82	6586	6.10	13452	6.23	29977	6.94
3435	5.73	7206	6.01	14671	6.11	32686	6.81
324	1.08	653	1.09	1169	0.97	2118	0.88
333	0.93	671	0.93	1202	0.83	2182	0.76
341	0.81	690	0.82	1236	0.74	2245	0.67
350	0.73	708	0.74	1270	0.66	2309	0.60
359	0.66	727	0.67	1304	0.60	2373	0.55
368	0.61	746	0.62	1337	0.56	2436	0.51
2465	8.22	5873	9.79	12146	10.12	26721	11.13
2818	7.83	6700	9.31	13844	9.61	30433	10.57
3171	7.55	7526	8.96	15541	9.25	34146	10.16
3524	7.34	8353	8.70	17238	8.98	37858	9.86
3887	7.20	9180	8.50	18936	8.77	41570	9.62
4230	7.05	10006	8.34	20633	8.60	45283	9.43
353	1.18	728	1.21	1504	1.25	3083	1.28
364	1.01	750	1.04	1549	1.08	3175	1.10
374	0.89	771	0.92	1593	0.95	3268	0.97
385	0.80	793	0.83	1638	0.85	3360	0.88
395	0.73	814	0.75	1683	0.78	3453	0.80
406	0.68	836	0.70	1728	0.72	3545	0.74
780	2.60	2500	4.17	3353	2.79	4807	2.00
813	2.26	2632	3.66	3528	2.45	5120	1.78
847	2.02	2767	3.29	3703	2.20	5434	1.62
880	1.83	2899	3.02	3878	2.02	5747	1.50
914	1.69	3031	2.81	4053	1.88	6057	1.40
948	1.58	3165	2.64	4231	1.76	6371	1.33

Table 49. Annual costs of waste handling and disposal options for system 4, with 500# of N allowed per acre and 21 disposal days

	System utilization, %	100 Total cost $	100 Cost per AU, $	200 Total cost $	200 Cost per AU, $
	50	85	1.70	131	1.31
	60	85	1.42	131	1.09
Settling basin and	70	85	1.21	131	0.94
detention lagoon	80	85	1.06	131	0.81
	90	85	0.94	131	0.73
	100	85	0.85	131	0.66
	50	260	5.20	470	4.70
	60	260	4.33	470	3.92
Manure pump(s)	70	260	3.71	470	3.36
	80	260	3.25	470	2.94
	90	260	2.89	470	2.61
	100	260	2.60	470	2.35
	50	578	11.56	643	6.43
	60	578	9.63	643	5.36
Liquid manure	70	578	8.26	643	4.59
tankwagon(s)	80	578	7.23	643	4.02
	90	578	6.42	643	3.57
	100	578	5.78	643	3.21
	50	282	5.64	284	2.84
	60	282	4.70	284	2.37
Injectors for liquid	70	282	4.03	284	2.03
manure tankwagon(s)	80	282	3.53	284	1.78
	90	282	3.13	284	1.58
	100	282	2.82	284	1.42
	50	649	12.98	740	7.40
	60	649	10.82	740	6.17
Vacuum liquid	70	649	9.27	740	5.29
manure tankwagon(s)	80	649	8.11	740	4.62
	90	649	7.21	740	4.11
	100	649	6.49	740	3.77
	50	263	5.26	266	2.66
	60	263	4.38	266	2.22
Injectors for vacuum	70	263	3.76	266	1.90
liquid manure	80	263	3.29	266	1.66
tankwagon(s)	90	263	2.92	266	1.48
	100	263	2.63	266	1.33
	50	489	9.78	549	5.49
Irrigation system:	60	489	8.15	549	4.58
Stationary big gun:	70	489	6.99	549	3.92
100-1199 AU	80	489	6.11	549	3.43
Traveling big gun:	90	489	5.43	549	3.05
1200-4800 AU	100	489	4.89	549	2.75

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $	Total cost $	Cost per AU, $
302	1.01	386	0.64	1039	0.87	2004	0.84
302	0.84	386	0.54	1039	0.72	2004	0.69
302	0.72	386	0.46	1039	0.62	2004	0.60
302	0.63	386	0.40	1039	0.54	2004	0.52
302	0.56	386	0.36	1039	0.48	2004	0.46
302	0.50	386	0.32	1039	0.43	2004	0.42
1311	4.44	1368	2.28	1482	1.24	2311	0.96
1311	3.64	1368	1.90	1482	1.03	2311	0.80
1311	3.12	1368	1.63	1482	0.88	2311	0.69
1311	2.73	1368	1.43	1482	0.77	2311	0.60
1311	2.43	1368	1.27	1482	0.69	2311	0.53
1311	2.19	1368	1.14	1482	0.62	2311	0.48
908	3.03	1058	1.76	2202	1.84	4110	1.71
908	2.52	1058	1.47	2202	1.53	4110	1.43
908	2.16	1058	1.26	2202	1.31	4110	1.22
908	1.89	1058	1.10	2202	1.15	4110	1.07
908	1.68	1058	0.98	2202	1.02	4110	0.95
908	1.51	1058	0.88	2202	0.92	4110	0.86
292	0.97	297	0.50	331	0.28	388	0.16
292	0.81	297	0.41	331	0.23	388	0.13
292	0.70	297	0.35	331	0.20	388	0.12
292	0.61	297	0.31	331	0.17	388	0.10
292	0.54	297	0.27	331	0.15	388	0.09
292	0.49	297	0.25	331	0.14	388	0.08
1109	3.70	1315	2.19	2894	2.41	5131	2.14
1109	3.08	1315	1.83	2894	2.01	5131	1.78
1109	2.64	1315	1.57	2894	1.72	5131	1.53
1109	2.31	1315	1.37	2894	1.51	5131	1.34
1109	2.05	1315	1.22	2894	1.34	5131	1.19
1109	1.85	1315	1.10	2894	1.21	5131	1.07
276	0.92	282	0.47	328	0.27	423	0.18
276	0.77	282	0.39	328	0.23	423	0.15
276	0.66	282	0.34	328	0.19	423	0.13
276	0.58	282	0.29	328	0.17	423	0.11
276	0.51	282	0.26	328	0.15	423	0.10
276	0.46	282	0.23	328	0.14	423	0.09
730	2.43	2129	3.55	2562	2.14	3269	1.36
730	2.03	2129	2.96	2562	1.78	3269	1.14
730	1.74	2129	2.53	2562	1.53	3269	0.97
730	1.52	2129	2.22	2562	1.33	3269	0.85
730	1.35	2129	1.97	2562	1.19	3269	0.76
730	1.22	2129	1.77	2562	1.07	3269	0.68

Table 50. Annual costs of waste handling and disposal options for system 5 with 500# of N allowed per acre and 21 disposal days

		100		200	
	System utilization %	Total cost $	Cost per AU $	Total cost $	Cost per AU $
Conventional manure spreader(s)	50	578	11.56	864	8.64
	60	633	10.55	977	8.14
	70	689	9.84	1090	7.79
	80	745	9.31	1203	7.52
	90	800	8.89	1315	7.31
	100	856	8.56	1428	7.14
Manure loader(s)	50	591	11.82	864	8.64
	60	644	10.73	971	8.09
	70	697	9.96	1077	7.69
	80	750	9.38	1182	7.39
	90	803	8.92	1287	7.15
	100	856	8.56	1392	6.96
Disc(s)	50	554	11.08	562	5.62
	60	555	9.25	565	4.71
	70	557	7.96	568	4.06
	80	559	6.99	571	3.57
	90	560	6.22	574	3.19
	100	562	5.62	577	2.89

Design space: Animal units

600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
2317	7.72	5239	8.73	11774	9.81	26333	10.97
2704	7.51	6115	8.49	13657	9.48	30472	10.58
3091	7.36	6991	8.32	15540	9.25	35610	10.30
3479	7.25	7867	8.19	17423	9.07	38749	10.09
3866	7.16	8742	8.09	19306	8.94	42888	9.93
4253	7.09	9618	8.02	21188	8.83	47026	9.80
1867	6.22	3240	5.40	7104	5.92	19104	7.96
2152	5.98	3780	5.25	8338	5.79	22579	7.84
2436	5.80	4326	5.15	9576	5.70	26040	7.75
2718	5.66	4867	5.07	10810	5.63	29453	7.67
2998	5.55	5400	5.00	12031	5.57	32832	7.60
3276	5.46	5928	4.94	13248	5.52	36192	7.54
593	1.98	640	1.07	735	0.61	923	0.38
603	1.68	659	0.92	772	0.54	999	0.35
612	1.46	678	0.81	810	0.48	1074	0.32
621	1.29	697	0.73	848	0.44	1149	0.30
631	1.17	716	0.66	885	0.41	1225	0.28
640	1.07	735	0.61	923	0.38	1300	0.27

Table 51. Annual costs of waste handling and disposal options for system 6 with 500# of N allowed per acre and 21 disposal days

	System utilization %	100 Total cost $	100 Cost per AU $	200 Total cost $	200 Cost per AU $
Conventional manure spreader(s)	50	588	11.76	894	8.94
	60	646	10.77	1012	8.43
	70	704	10.06	1131	8.08
	80	761	9.51	1250	7.81
	90	819	9.10	1369	7.61
	100	877	8.77	1487	7.44
Manure loader(s)	50	594	11.88	872	8.72
	60	647	10.78	978	8.15
	70	700	10.00	1082	7.73
	80	752	9.40	1186	7.41
	90	804	8.93	1290	7.17
	100	856	8.56	1392	6.96
Disc(s)	50	562	11.24	577	5.77
	60	565	9.42	584	4.87
	70	568	8.11	590	4.21
	80	571	7.14	596	3.73
	90	574	6.38	603	3.35
	100	577	5.77	609	3.05

Design space: Animal units							
600		1200		2400		4800	
Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $	Total cost $	Cost per AU $
3015	10.05	6240	10.40	13863	11.55	29926	12.47
3518	9.77	7287	10.12	16055	11.15	34616	12.02
4020	9.57	8335	9.92	18248	10.86	39305	11.70
4523	9.43	9383	9.77	20441	10.65	43994	11.46
5026	9.30	10431	9.66	22633	10.48	48684	11.27
5529	9.22	11479	9.57	24826	10.34	53373	11.12
1796	5.99	3223	5.37	7428	6.19	19368	8.07
2063	5.73	3755	5.22	8712	6.05	22867	7.94
2328	5.54	4280	5.09	9979	5.94	26376	7.85
2718	5.66	4799	5.00	11251	5.86	29914	7.79
2851	5.28	5292	4.90	12463	5.77	33480	7.75
3109	5.18	5819	4.85	13728	5.72	37104	7.73
640	2.13	735	1.23	923	0.77	1300	0.54
659	1.83	772	1.07	999	0.69	1451	0.50
678	1.61	810	0.96	1074	0.64	1602	0.48
697	1.45	848	0.88	1149	0.60	1753	0.46
716	1.33	885	0.82	1225	0.57	1904	0.44
735	1.23	923	0.77	1300	0.54	2055	0.43

CHAPTER VI. SUMMARY AND CONCLUSIONS

The structure of the cattle feeding industry in Iowa and the United States is continually changing. New technologies and varieties of feed grains have influenced some cattle feeders to greatly increase their fed cattle output. On the other hand, higher grain prices and the risk of cattle feeding has influenced some other cattle feeders to drop out of cattle feeding altogether.

In general, convenience and an increasingly scarce supply of inexpensive farm labor has influenced new cattle feeding technologies to become more capital intensive. Therefore, livestock feeding operations which need not be land based, tend to become specialized autonomous units capable of spreading high fixed costs over a large concentrated volume of animal units. This adjustment has been necessary to allow the feeder to be economically competitive. The result has been increased confinement of livestock and increased numbers of animals per livestock operation.

Such changes in the cattle feeding industry have created new problems, not the least of which is how to "dispose" of the waste produced by these animals, economically and without harming the environment. Previously, the problem was just a matter of "hauling manure" from the barnyard to the fields. Now, however, "waste management" is required.

Since the increased concentration of animal numbers and the increased awareness of society about pollution problems no longer allows us to just haul manure, we need improved information about the alternatives in waste management. Basic answers are needed to the questions of what are the costs involved and who will ultimately bear them. Feedlot operators, politicians, and consumers all have a vested interest in this problem.

The first objective of this study was to develop an analytical tool to help evaluate some beef cattle waste management systems. This objective was attained by developing a heuristic simulation model of various beef feedlot types and some of their waste handling alternatives. The basic core of the model is construed as much as possible of technological and mathematical facts. A large portion of the model involves parameters, which can be updated to accommodate a rapidly changing industry and specific situations.

In the previous chapter, farmer-feeders were assumed to operate in a world consistent with the assumptions made in a given run of the model. This alludes to one of the difficulties related to problem or system analysis. By the time the problem or system can be thoroughly studied, the value of some parameter may have changed. If actual operating systems are surveyed and studied, the data are almost out of date by the time the study is completed. With the modeling approach, if the central Iowa farmers land is more nearly worth $2000

per acre rather than the $800 per acre assumed, the value per acre parameter can be changed, the model operated and the updated results can be obtained almost immediately.

The second objective of this study was to use the model developed to evaluate the effect of various restrictions on waste handling practices. This objective was attained by operating the model under the three alternative assumptions given at the beginning of Chapter V. They involve the amount of nitrogen that can be applied to an acre of land and the amount of time the feedlot operator has available to dispose of the feedlot waste. The results of these three runs are given in the tables of Chapter V. The tables can be subdivided for comparison as follows.

Investment requirements for waste handling and disposal options under:

Alternative 1:	Tables 18-22
Alternative 2:	Tables 23-27
Alternative 3:	Tables 28-32

Annual costs for waste handling and disposal options under:

Alternative 1:	Tables 34-39
Alternative 2:	Tables 40-45
Alternative 3:	Tables 46-51

The investment requirements and annual costs of the animal confinement facilities are not affected by changing the alternative assumptions because they are the same under all the conditions used.

In general, higher investments are required in waste handling and disposal equipment under the more restricting levels of time and nitrogen application. However, in the smaller feedlots, some excess capacity (because of "lumpy" inputs) in waste handling equipment and available disposal time result in no change in investment requirements between the three alternatives. For example, the cold confinement-deep pit system (System 2), at the 100 animal unit level, requires an investment of $2500 for liquid manure tankwagons under all three alternatives. However, at the 1200 animal unit level an investment of $9000, $5900, and $5000 is required for alternatives 1-3 respectively.

Annual costs show a similar reaction to the restrictions. The excess in capacity of equipment and available time in the smaller lots is reflected in the little or no change in their costs as they operate under each of the restrictions. In looking at the cold confinement-deep pit system again we see that the annual costs per animal unit (at 100% of capacity), for the liquid manure tankwagon in the 100 animal unit lots, are $9.90, $9.90, and $9.70. The only difference between alternative 1 and alternative 2 is the amount of time available for disposal (14 vs. 21 days). It doesn't take 14 days to dispose of the manure from 100 animal units under the given technologies, thus the additional time allowed under alternative 2 has no bearing on the 100 AU lots. Under alternative

3, 500 pounds of N is allowed per acre rather than the 250 pounds in alternatives 1 and 2. The decrease in cost reflected under alternative 3 reflects spreading the given amount of manure over less acres.

At the 1200 animal unit level of System 2, the annual per AU costs (at 100% of capacity) of $7.29, $7.04, and $6.72 for alternatives 1-3 respectively, reflect the lower costs associated with more relaxed levels of control.

We have looked at only one specific example relating to changes in costs caused by tighter restrictions on waste disposal. There are numerous comparisons that may be made in the tables. The three alternative assumptions made, were made about parameters in the model that can be varied. Therefore other comparisons could be made under different assumptions. The "what if--?" possibilities are numerous. The model developed is flexible--yet specific. It is a tool that can derive the costs of certain waste management alternatives under a wide range of conditions. Hopefully this will be helpful in determining which alternatives should be pursued.

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